VOLUME 28 NUMBER 10

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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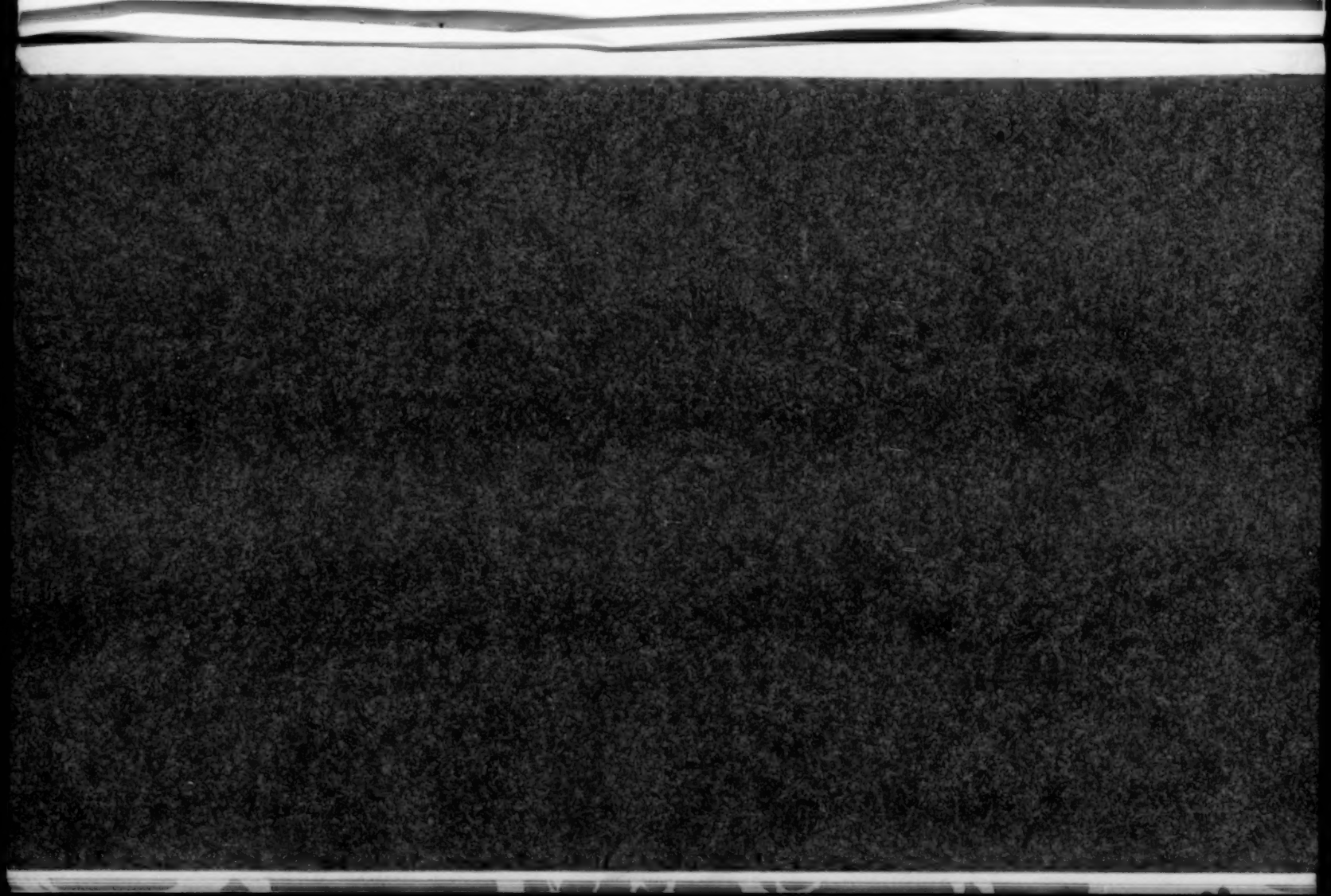

JUNE, 1907 VOL. 28 No. 10

THE AMERICAN SOCIETY OF
MECHANICAL ENGINEERS

PROCEEDINGS

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
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The professional papers contained in Proceedings are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present. They are issued to the members in confidence, and with the understanding that they are not to be published even in abstract, until after they have been presented at a meeting. All papers are subject to revision.

The Society as a body is not responsible for the statements of facts or opinions advanced in papers or discussions.

Proceedings is published twelve times a year, monthly except in July and August, semi-monthly in October and November. One copy of each issue without charge to members.

Price, one dollar per copy—fifty cents per copy to members. Yearly subscription, $7.50; to members, $5.00.

PROCEEDINGS

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOL. 28 . JUNE 1907 NUMBER 10

THE Council decided at its meeting on April 16 that—as heretofore the Society had not held regular monthly meetings and that as such monthly meetings had not been specifically mentioned in the Constitution and By-Laws or Rules of the Society as having official recognition—it was the sense of the Council that monthly meetings now be considered as official, and that they offer equal opportunity with the annual and spring meetings for the presentation of technical papers and discussions, and that the same shall be considered by the Publications Committee for the Transactions equally as if they had been presented at the annual or spring meeting.

NEW JUNIOR BADGE

The Membership Committee, with the approval of the Council, has adopted a new badge for the Junior grade of membership. The badge will be of the same design and form as the Member's badge, but will be crimson instead of blue. The reason for the change is that the old form of Junior badge is unlike the recognized emblem of the Society, and on that account is not satisfactory. The new badge successfully meets this criticism.

Members of the Junior grade desiring to exchange old Junior badges for the new, will be allowed credit according to the condition of the badge returned.

The cost of the new Junior badge is $3.25, the same as that of the Member's badge.

PRESENTATION OF PORTRAIT OF GEORGE H. CORLISS

The portrait of George H. Corliss has been presented to the Society by Mrs. George H. Corliss and Miss Corliss. The formal presentation was made by Professor Hutton on Thursday evening of Dedication week, before a distinguished audience which had gathered to listen to the address of Brigadier-General William Crozier.

The Council has expressed to Mrs. Corliss and Miss Corliss the appreciation of the Society for the portrait.

HONORARY VICE PRESIDENTS

The President of the Society has designated Prof. Ira H. Woolson of Columbia University, New York, and Mr. John R. Freeman, 815 Banigan Building, Providence, R. I., as Honorary Vice Presidents to represent the Society at the Convention of the National Fire Protection Association.

INDIANAPOLIS NOTES

The Spring Meeting will be held in Indianapolis, Indiana, May 28-31. The headquarters room will be on the parlor floor of the Claypool Hotel, and the professional sessions on the top floor on the south side of the building. Seventy-five rooms have been reserved for convention guests. Members who desire to have accommodations reserved should correspond with the hotel authorities at once.

The Secretary cannot undertake to reserve rooms for members or guests at the hotels in Indianapolis. Members must communicate direct with the hotel at which they desire to stop.

Special warning is given that hotel reservations should be secured at once to avoid disappointment owing to the unusual demand for rooms because of the presence of the President of the United States in Indianapolis on Decoration Day.

In addition to the Bulletin mailed to the membership, the Local Committee in Indianapolis is preparing a booklet that will contain full hotel information with a map of the city showing hotels marked upon it, names of the hotels, description, rates and how to reach them from the station; a general description and historical sketch of the city of Indianapolis showing points of general interest with illustrations: a description of points of engineering interest, the Filtration Plant, Gas Works, etc., and description of plants, all places mentioned in the booklet being marked on the map.

The Secretary regrets that after repeated efforts it has been impossible to secure any uniform rate for the transportation of the members of the Society to and from the convention, owing to recent legislative enactments in several states establishing a two cent rate, and owing also to the inter-state tariff law. Read the Transportation Notice carefully.

One or more private Pullman sleeping cars will be reserved on each of two trains from the East. These reservations will be made only in case the number of applications received for Pullman accommodations reach the minimum set by the company. Address applications for these special reservations to S. E. Whitaker, Office Manager of the Society.

To obtain special rates from New York, Pennsylvania, New Jersey, Delaware and Maryland a member must obtain a special card from S. E. Whitaker, Office Manager of the Society, and present this card to the ticket agent when he buys his ticket. Failure to have this card means that he must pay full fare. Send applications for card to Mr. Whitaker before May 23. We cannot promise to honor requests for the card after that date.

The official headquarters will be opened in the Claypool Hotel at noon on Tuesday, May 28, and maintained throughout the meeting. Members and guests are requested to register as early as possible. No guest will be registered unless he brings with him a letter of introduction from the member whose guest he is, or unless the member personally registers for him.

The University of Illinois extends to the Members of the Society attending the Convention in Indianapolis a cordial invitation to visit the University where they will be received by Dr. L. P. Breckenridge, Professor of Mechanical Engineering, and Director of the Government Research Station. Those who take advantage of this invitation will find the trip to Urbana very pleasant and profitable.

The Local Committee at Indianapolis consists of Mr. J. R. Whittemore, General Chairman; Mr. L. M. Wainwright, Chairman Finance Committee; Mr. William Rockwood, Chairman Ladies Committee; Mr. H. H. Rice, Chairman Entertainment Committee; Mr. W. G. Wall, Chairman Hotel Committee; Mr. Theo. Weinshank, Chairman Printing and Press Committee; Mr. Russell M. Leeds, Advertising Manager.

DISCUSSION

Cards containing a list of the papers to be presented at the Indianapolis Meeting, all of which have been published in the April, May, and in this number of Proceedings, are being mailed to the members with the request to indicate what papers they expect to discuss, and whether the discussion will be written or oral.

It is necessary that these cards be returned to the Secretary's office by May 22, if the name as a contributor to the discussion is to appear in the program.

Attention is called to the usual procedure at meetings which is to give precedence to those who have advised the office in advance of their intention to discuss certain papers.

Written discussion must be in the office by May 25.

HOTEL ACCOMMODATIONS

The Claypool has been selected as the official hotel for the Indianapolis meeting, May 28 to 31, 1907, the headquarters of the Society during the convention, and the meeting place for the professional sessions except the one which will be held at Purdue University.

Members who expect to attend the meeting and desire accommodations at any of the hotels listed below will please communicate directly with the house they select as to what they will require. They are advised to do so as early as convenient, thus avoiding chance of being disappointed as to the accommodations they may desire.

The visit of President Roosevelt to Indianapolis on Decoration Day means that the hotels will be crowded at the time of our Spring Meeting with people from all parts of the State.

THE CLAYPOOL

American plan: single room without bath $3.50 per day and upward, single room with bath $4.00 per day and upward. When two or more persons occupy the same room, without bath $3 or $3.50 per day for each person, with bath $3.50, $4 or $4.50 per day for each person.

European plan: single room without bath $2 per day and upward, single room with bath $2.50 per day and upward. When two or more persons occupy the same room, without bath, $1.50 or $2 per day per person, with bath, $2 or $2.50 or $3 per day per person.

THE DENISON HOTEL

European plan: room without bath $1 and $1.50 per day, with bath $2 per day; en suite, $2.50 to $4 per day. Accommodates 200.

THE GRAND HOTEL

American plan: without bath $2.50 per day and upward, with bath $3.50 per day and upward.

THE NEW HOTEL ENGLISH

American plan: room without bath $2, $2.50 per day and upward, room with bath $2.50, $3, $3.50 per day and upward.

European plan: room without bath $1, $1.50 per day and upward, room with bath $1.50, $2, $2.50 per day and upward.

When two persons occupy the same room, the same rates per person prevail.

PROGRAM

OPENING SESSION

Tuesday evening, May 28, at 9 o'clock

In the Auditorium of the Claypool Hotel

Address of welcome by Mayor Bookwalter.

Response by Prof. F. R. Hutton, President of the Society.

A Social Reunion and informal reception will be held after the opening address, which will give an opportunity for members and guests to meet the friends of Indianapolis and exchange greetings. Ladies will be especially welcome.

SECOND SESSION

Wednesday morning, May 29, 9.30 o'clock

Business Meeting. Reports of the Tellers on Election of Members and Report of Standing and Special Committees. New business can be presented at this Session.

"Report of the Committee on Standard Proportions for Machine Screws."

"Preliminary Report of the Committee on Refrigerating Machines."

"Collapsing Pressures of Lap Welded Steel Tubes," R. T. Stewart.

"The Balancing of Pumping Engines," A. F. Nagle.

"The Economy of the Long Kiln," E. C. Soper.

INSPECTION TRIPS

Wednesday afternoon, May 29

Two special excursions have been planned by the Local Committee to plants of unusual interest.

THIRD SESSION

Wednesday evening, 8.15 o'clock

AUTOMOBILE SYMPOSIUM

"Ball Bearings," Henry Hess.
"Air Cooling of Automobile Engines," John Wilkinson.
"Materials for Automobiles," Elwood Haynes.
"Special Auto Steel," T. J. Fay.
"Railway Motor Car," B. D. Gray.

FOURTH SESSION

Thursday morning, May 30, 9 o'clock

SUPERHEATED STEAM

"The Specific Heat of Superheated Steam," A. R. Dodge.
"The Flow of Superheated Steam in Pipes," E. H. Foster.
"Furnace and Superheat Relations," R. P. Bolton.
"The Determination of Entropy Lines for Superheated Steam," A. M. Greene.
"The Heating of Store Houses," H. O. Lacount.

EXCURSION

Thursday afternoon, May 30

Excursions are planned to various points of interest in and around Indianapolis.

RECEPTION

Thursday evening, May 30, 9 o'clock

The reception will be held in the assembly room at the Claypool Hotel at 9 o'clock. This is the distinctively social feature of the meeting and the attendance of the ladies is particularly desired. It is urged that no one shall remain away because the exigencies of travel have made evening dress inconvenient.

FIFTH SESSION

Friday morning and afternoon, May 31

EXCURSION TO PURDUE UNIVERSITY, LAFAYETTE, IND.

A professional session will be held at 10 a. m. in one of the University buildings.

"Performance of Cole Superheaters," W. F. M. Goss.

"Experiences with Superheated Steam," G. H. Barrus.

"Superheated Steam in an Injector," S. L. Kneass.

"Use of Superheated Steam on Locomotives in America," H. H. Vaughan.

"Analysis of Locomotive Tests," S. A. Reeve.

"Materials for the Control of Superheated Steam," M. W. Kellogg.

RAILWAY TRANSPORTATION NOTICE

Arrangements for hotel, transportation and sleeping car accommodations should be made personally by each person attending the meeting.

SPECIAL TRAIN ARRANGEMENTS

One or more private Pullman sleeping cars will be reserved on each of four trains from the East. These reservations will be made only in case the number of applications received for Pullman accommodations reach the minimum set by the company. Address applications to Mr. S. E. Whitaker, Office Manager.

The first train selected is the "St. Louis Express" via. P. R. R., which will leave New York on Monday and arrive in Indianapolis during the afternoon on Tuesday. The first session of the meeting will be on Tuesday evening. The schedule for this train will be as follows:

Lv.	New York, Monday, May 27	6.25 p. m.
"	Philadelphia	8.58 p. m.
"	Pittsburg	5.37 p. m.
Ar.	Indianapolis, Tuesday, May 28	3.05 p. m.

The second train selected is the "Pennsylvania Limited," which leaves New York on Tuesday and arrives in Indianapolis on Wednesday in time for the first professional session. New York members going by this train can have two hours in their offices on Tuesday.

Lv.	New York, Tuesday, May 28	10.55 a. m.
"	Philadelphia	11.10 p. m.
"	Pittsburg	8.55 p. m.
Ar.	Indianapolis, Wednesday	6.55 a. m.

The third train is the "Lake Shore Limited," via N. Y. C. R. R.

Lv.	Grand Central Station, New York, Monday, May 27	5.30 p. m.
"	Albany	8.55 p. m.
"	Utica	11.12 p. m.
"	Syracuse	12.30 a. m.
"	Rochester	2.18 a. m.
Ar.	Indianapolis, Tuesday, May 28	3.00 p. m.

The fourth train is the "Southwestern Limited," via N. Y. C. R. R.

Lv.	Grand Central Station, New York, Tuesday, May 28.	2.00 p. m.
"	Albany	5.19 p. m.
"	Utica	7.23 p. m.
"	Syracuse	8.42 p. m.
"	Rochester	10.36 p. m.
Ar.	Indianapolis, Wednesday, May 29	10.50 a. m.

FROM CHICAGO

The train out of Chicago via "Big Four" upon which a special car will be run if the number of reservations warrants it, will reach Indianapolis in time for the opening session Tuesday evening. It is believed that our members and their guests will be glad to coöperate to secure this additional opportunity for social intercourse with old friends. The schedule will be:

Lv.	Chicago, Tuesday, May 28	1.00 p. m.
Ar.	Indianapolis	6.20 p. m.

REGARDING SPECIAL RATES

The Secretary regrets that after repeated efforts, it has been impossible to secure any uniform rate of transportation of the members of the Society to and from the convention. Owing to the enactment of two cent fare laws by the legislatures of a number of States in the territory included under the jurisdiction of the Central Passenger Association, and by reason of these material reductions in their passenger revenue, the transportation lines in this Association are compelled to modify the arrangements they have made for many years for convention travel.

The Central Passenger Association, in whose territory Indianapolis is located, announce a rate of two cents per mile in each direction from points in their territory. Tickets of signature form will be sold on May 27, 28 and 29 and will be good for return to leave Indianapolis to and including, but not later than June 1. Provision will be made for the validation of these tickets at the Indianapolis ticket office. This Association comprises the following territory:

The portion of Illinois south of a line from Chicago through Burlington to Keokuk and east of the Mississippi River, the states of Indiana, and Ohio, the portion of Pennsylvania and New York north and west of the Ohio River, Salamanca and Buffalo, and that portion of Michigan between Lake Michigan and Huron.

The Trans-Continental Passenger Association announce one first-class thirty day fare for the round trip from California, for instance,

to Chicago and return $72.50, to St. Louis and return $67.50. These tickets are on sale on two days only, May 20 and 21, and may be purchased, going via any regular direct route, returning via the same or any other regular direct route. Stop-overs will be allowed between the California line and Chicago. The purchaser must reach his destination within 10 days of date of sale. Tickets are good for return within 90 days of date of sale. This Association also announces the regular nine months rates to Chicago and St. Louis; these approximate two cents per mile in each direction, or about one fare and one-third for the round trip. The territory includes:

California, Nevada, Oregon, Washington and west of and including Mission Junction, B. C., including also Kootenay common points, Nelson, Rossland, Sandon, Caslo, and Grand Forks, B. C.

The Trunk Line Association announces a special rate of two cents per mile in each direction from points in their territory. To buy your ticket at this special rate, it is absolutely necessary

a to secure a special card from the Office Manager;

b to present this card to the ticket agent when the ticket is purchased.

Applications for the special card must reach Mr. Whitaker not later than May 23. Failure to present the card means failure to obtain the reduced rate. Tickets will be of signature form, to be signed by the purchaser at time of purchase. They may be bought only on May 26, 27 and 28 and will be good for return to leave Indianapolis to and including but not later than June 1. The return route of the tickets will be the same as the outgoing route. Stop-overs at Philadelphia, Baltimore, Washington and Niagara are allowed within the return limits of the ticket. This association includes the following territory:

All of New York east of a line running from Buffalo to Salamanca, all of Pennsylvania east of the Ohio River, all of New Jersey, Delaware and Maryland; also that portion of West Virginia and Virginia, north of a line running through Huntington, Charleston, White Sulphur Springs, Charlottesville and Washington, D. C.

With the New England Passenger Association negotiations are pending whereby we hope to secure special rates with conditions similar to those announced by the trunk line association. The territory includes:

Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut.

Members living in these states, who intend to go to the Convention, are requested to write at once to Mr. Whitaker for special information as to rates.

DEDICATORY EXERCISES

The Dedication of The Engineering Societies Building

On Wednesday afternoon, April 17, the Dedicatory Exercises were continued, when John W. Lieb, Jr., presided as Chairman.

OPENING ADDRESS BY CHAIRMAN JOHN W. LIEB, JR.

Ladies and Gentlemen: In the dedication exercises of yesterday we gave expression to the deep gratitude of the engineering profession to Andrew Carnegie for his splendid gift; and our honored guests, distinguished visitors, and fellow society members, have enjoyed the opportunity of inspecting the building and its equipment, and of observing how completely architect and building committee, in harmonious coöperation, have succeeded in the difficult task of meeting the unusual requirements, and for which there existed no precedent.

The simple plain language in which the gift was conveyed—"It will give me great pleasure to devote say one million and a half dollars to erect a union building for you all"—and which will be preserved to history on the bronze memorial tablets opposite the entrance, reflects the broad and liberal spirit of the donor, and it also placed upon the recipients the full responsibility of building wisely and administering efficiently.

We meet today under the auspices of the Founders Societies—The American Institute of Electrical Engineers, The American Society of Mechanical Engineers, and The American Institute of Mining Engineers—to receive the greetings and felicitations of foreign and national engineering societies and institutions of learning, and for the interchange of congratulations between the members of the Founder Societies and associate societies on the successful completion of this magnificent building.

This being Founders' Day it may not be inappropriate, having given Mr. Carnegie our tribute of appreciation for his munificence and liberality, that we should also say a word for the members and friends of the Founder Societies. The Founder Societies, in order to

reach the condition which has enabled them to take upon themselves the responsibility of erecting this great building on land for which they have assumed the obligation, have also been hard at work, and the different Societies, assisted by gifts which their members have made from time to time, have arrived at a condition where it has been possible to assume this obligation.

The Founder Societies have been the recipients of magnificent gifts—in many cases, of complete and valuable libraries. These libraries are today the nucleus of a splendid collection of engineering literature which will undoubtedly grow into the greatest engineering and scientific library in the world.

A word should also be said of the work which was done by the members of the Conference and Building Committees who have not been formally presented in the preceding exercises. To name them all, and to award to each the degree of praise to which he is entitled would be a difficult undertaking; suffice it to say that every member of these Committees has coöperated valiantly in this great work, so that up to the present time we have had the good fortune of moving along in the utmost harmony without friction or clash of any sort.

On behalf of the Founder Societies I beg leave to extend to the distinguished representatives of sister societies and of the institutions of learning who honor the occasion with their presence, our most hearty thanks for the interest they have shown by taking part in our dedication exercises, and we bid them thrice welcome.

It is with particular pleasure that we extend our warmest greetings to the eminent representatives of sister societies from abroad. To them we extend the hand of professional fellowship and we ask them to share with us the joys of these festivities.

Engineers have ever been leaders in promoting international friendships, and by their international congresses and the interchange of visits between foreign societies they have established the most enduring cordiality of relations between large bodies of influential men, separated, it is true, by national boundaries, but having common professional ideals and the same spirit of enlightened progress.

We may, in fact, at this time rightly consider ourselves a kind of auxiliary to the great International Peace Congress which is now meeting in this city. The engineering societies are now enjoying, through the generosity of Mr. Carnegie and the coöperation of their friends and members, the realization of the fond hopes which they have cherished for years, and with the opening of this building there opens also a new era for the engineering profession in this country.

The magnificent facilities which the societies have now at their disposal should go far toward making coöperation among the various branches of the engineering profession more effective—securing to the engineer that high standing in the community to which his accomplishments, both literally and constructively speaking, justly entitle him.

We also welcome the representatives of the associate societies who with us enjoy these opportunities, and who coöperating with the engineers in the industrial applications of engineering science, also share in their triumphs.

We hope that to our guests and friends, as well as to the membership of our engineering societies, these spacious halls and pleasant meeting rooms may be a new source of inspiration, awakening a greater pride in the profession we have chosen, and dedicating ourselves and you to the pursuit of the highest professional ideals, to the increase of human knowledge, and to the advancement of civilization.

I will call upon the representatives of the Founder Societies, and now present Dr. Samuel Sheldon, President of The American Institute of Electrical Engineers.

ADDRESS BY SAMUEL SHELDON, PRESIDENT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

MR. CHAIRMAN, LADIES, AND GENTLEMEN

Even a casual visitor to the edifice whose dedication is the occasion of the present festivities, must be impressed by its simplicity, its beauty, and its substantiality. The personnel of the executive departments of the associated societies that have here domiciled themselves recognize its fitness and its spaciousness. All these qualities will endure except the last. The future will doubtless bring a congestion of occupancy which seems to be an inevitable metropolitan characteristic.

The Founder Societies at the present time have a total membership of about 12,000. Of these 5 per cent live in New York or in its vicinity and to them this building is accessible. More than eight associate societies with an approximate membership of 4000 are also at home here, nearly 40 per cent of whom dwell in this vicinity. An inspection of the curves of growth of membership in the three Founder Societies shows that the enrollment will be doubled in 1920, if past policies of management be maintained. Even times of financial depression do not lessen the membership but lessen its rate of growth.

But the short period of joint occupancy just elapsed has evidenced a stimulation to increased activity which, if maintained, will make membership more desirable, and a greater increment may be expected.

During the past few years there has been a rapid growth in civilization, and commerce, traffic, manufactures, organizations, fortunes, knowledge, and individual efficiences have increased. Excessive and extraordinary growth has resulted from the efforts of the Electrical Engineers. Doubtless this is due to the youthfulness of the profession, whose oldest workers are not thinking of retirement but on the contrary are enthusiastically and energetically productive.

Rapid growth and the character of his work necessitates that the engineer shall continually deal with the probabilities of the future. The remarkable economies resulting from an extensive engineering study based upon more or less uncertain future conditions, of the problem of supplying telephone service in New York twenty years hence, were called to the attention of the members of The American Institute of Electrical Engineers in a recent paper. We are all familiar with the frantic struggles of engineers in charge of public utility central stations in their efforts to have modern apparatus manufactured, purchased, and installed quickly enough to carry the ever increasing load, but not so quick as long to stand idle and bring down the wrath of the financier. Reprehensible neglect to consider future conditions has resulted in an intolerable congestion of traffic in certain parts of this city. One cannot but admire the circumspection of the engineer who designed the bridges of the Western Railroad in Massachusetts, so as to carry two tracks, although the practicability of the steam locomotive had not as yet been demonstrated, and a double track road had not been seriously contemplated. One cannot but regret that the engineer who let his rule slip when he established the standard track gage at 4 feet 8½ inches had not the circumspection to let it slip in the other direction, that thereby there might have been a present amelioration of the troubles of the Great. But all must congratulate those who engineered the construction of this building that they, like the Prophets of Biblical times, like all good generals in times of war, and like all good statesmen in times of peace, looked into the future in designing this our home.

The constitution of The American Institute of Electrical Engineers states that "Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the Arts and Sciences connected with the production and utilization of electricity."

The results of recent scientific investigation show that it does not lie within the power of man to produce electricity, and accumulated

experience preëmpts to the electrical engineer the transformation of other forms of energy into electrical energy, its transmission and its adaptation for purposes of utilization. To the efficient, flexible, and convenient manner in which these things can be done is due the development of the art. The accomplishment of this work has brought about a natural classification of the workers into, first; those who design, manufacture, and adapt apparatus; second, those who purchase, erect, and install it, and third, those who operate and maintain it. Economic evolution has placed the manufacture in the hands of a few large corporations that require for their work the coöperation of all types of human endeavor. In their employ are to be found, besides those found in every other industrial organization, engineers of all kinds, even military and naval.

Because of the great magnitude of modern engineering undertakings and the desire for high efficiency, there is a marked tendency to entrust the purchase, erection, and installation of electrical apparatus to large engineering organizations. Such an one in the West, whose head is a prominent electrical engineer, includes in its staff one or more electrical, civil, mechanical, structural, sanitary, chemical, gas, hydraulic, mining, industrial, and operating engineers. The natural results of the existence of such an organized staff is the undertaking of other than electrical installations. A firm in New York besides the installation of electrical railways, power, and lighting plants, is engaged in the construction of sewerage systems, and in the erection of banks, theaters, hotels, terminal stations, and other large structures. To such an organization the financing and engineering construction of the Panama canal would be a natural and feasible undertaking.

To those engineers who are engaged in the operation of electrical plants generally falls the task of purchase, erection, and installation of additional equipment necessitated by growth. Upon their staffs are also to be found various types of engineers.

These instances merely illustrate the condition of man's limitations because of his environment, and emphasize that the social fabric rests upon the interdependence of individuals and the redemptive economy that results from correlation of individual efforts. Try as we may to limit the spheres of our activities and to direct the lines of our intellectual growth, the potentiality of its seeds is beyond our control, and fortunate are we that there now portends an appropriate nourishment in the intercourse between the cohabitants of our new home.

MR. LIEB We will next have the pleasure of hearing from The American Society of Mechanical Engineers, and I will call upon Dr. Frederick R. Hutton, its President.

ADDRESS BY F. R. HUTTON, PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

MR. CHAIRMAN, LADIES, AND GENTLEMEN

He who would fain speak in any adequate way as a representative of the profession of mechanical engineering and of its practitioners in the American Society must recognize that the field of his outlook is exceedingly broad.

The electrical engineer has made his own the field of transmission of energy for light and power, and for transportation by railway, and for communication between individuals.

The mining engineer and metallurgist have conquered the winning of buried wealth from the earth and the process of making it available for industry and the production of wealth.

The function of the mechanical engineer has, therefore, been to share with the civil engineer the industrial activities in the rest of the field of practical achievement.

If to the latter be assigned the permanent way of the railroad and the highway and their bridges, the canal, the municipal field in waterworks and draining, and the designing of the braced structure as his specialities, there remains to the mechanical engineer the duty of generating or liberating power for all sorts and conditions of engineers, and the duty of design and creation of apparatus for the broad field of manufacturing. It would appear, therefore, that he will be most generally representative of mechanical engineering who places himself in the area devoted to the generation of power, which underlies all production on a large scale. He is also the one who creates machinery and tools for manufacturing and production in all lines, and who concerns himself with the operation of such plants and the consequent creation of wealth. I believe that the mechanical engineer of the twentieth century is to be the manufacturing engineer.

If the foregoing be conceded, then the dedication of the Engineers' Building at this time emphasizes the noteworthy economic significance of such a building. It has become, therefore, the gift of a great Producer to the great Factors of Production.

The owner of a mine is not enriched until by the expenditure of skill, power, and labor, the buried ore has been won and made available. The crude ore at the surface is not of full value until the

engineer of transportation by land or water has brought it to the door of the metallurgical engineer, who by expending skill, power, and labor upon it, changes it to useful metal. The metal is not of market value until the mechanical engineer by skill, power, machinery, and labor, has brought the metal to its merchant forms in which it can be sold and used.

In the next stage and after the purely productive process over which engineers have presided, will come the industrial or commercial application of the materials. For these again it is the engineer who has created the need. The railway, rail, the beam, the plate, the bar, the casting, and the forging are all made and sold to meet the call of the designer, the builder, and the user of the constructive elements in modern production. For all the wealth represented in plant and product it is an engineer who has signed the call. It is his rubbing of the Aladdin lamp of knowledge and skill, which has brought into existence the material result. It is a tribute to the insight and ideals of the donor of the building that he should have seen that by helping to foster the engineer himself he has raised a most notable monument to economic betterment and the uplift of the community. The building, supplying facilities for engineers' meetings, for an engineers' library, and for the executive work of engineering organizations has helped to raise and to advance the already exalted standard of that great profession within its own bounds.

But the Engineers' Building has not alone a meaning and significance to those who are to be within it and who benefit so directly by its provisions for comfort and for progress. It has an external significance and a meaning to those who are without. It stands in dignity and majesty as a public building on an eminence to deliver to luxury and thoughtlessness its uplifting message. It stands to teach that wealth or mere accumulation does not create or perpetuate itself until it is used. All consequent possibility of culture, education, refinement, and art are latent in wealth, but lie hidden there until it is devoted to industrial production. Mere manipulation of securities or purely capitalistic financing does not produce wealth. In manipulation, wealth may change owners, but one is poorer because the other is richer. The Engineers' Building stands for the real creation of community wealth where a real asset of value is made to enrich both owner and community by multiplying itself in accordance with physical and economic law. No production of wealth is real or can continue which is in defiance of law or fact. The engineers for whom this building exists are students and practitioners of their craft and

avocation in conformity with such law. Knowledge of such necessary laws lies at the base of the prosperity which the community enjoys.

This makes the Engineers' Building at once a beacon and a plea for engineering education. This must be such training as shall fit the engineer to conduct continuous and successful production in accordance with the requirements of physical and economic law. The scientist and the laboratory worker and the man of affairs must be looked to to discover, formulate, and apply these laws. The building is, therefore, a monument to what the engineering school and the scientist have done and are yet to do for the advancement of our civilization in educating its engineers.

Finally the Engineers' Building stands to rebuke certain economic fallacies. It is a convincing answer to a contention that physical toil and manual labor of arm and brawn are the only real creators of wealth in the production process and that the reward of toil is to be directed entirely to him who contributes bodily effort. It says to such a theorist that misdirected toil and labor which goes for naught through ignorance of physical or economic law will impoverish the community, not enrich it. Experiments are costly, when at their basis lie assumptions contrary to fact and truth. Furthermore, labor must be organized and must be directed by knowledge; its tools and its operations must also be designed and planned on a basis of knowledge and experiment. The director and organizer of labor is therefore to be compensated both practically and in public consideration in proportion to his economic value. The engineer as a factor in production far transcends the significance of the mere craftsman and this building evidences the truth and the fact. The economic future does not lie amid the dreariness of some of the contentions of the socialist. It lies in releasing more and more the human unit from the stress which we lay upon the beast of burden. In this releasing process the engineers will be inevitably the leaders.

In conclusion, therefore, I ask you to agree with me in these three contentions:

a That this building is a gift to favor production as a factor in creating wealth, itself an antecedent to progress in art, civilization, culture, and literature.

b That it should stand in its city as a monument for sound thinking on the position of the engineer and his relation to wealth and its production by knowledge and by skill working in accordance with natural law, and therefore for the significance of engineering education as favoring such sound thought.

c That as a consequence of these the community as a whole as well as the organizations directly benefited by the building owe a debt of obligation and recognition to him who has made all this possible.

MR. LIEB I will now call upon the President of The American Institute of Mining Engineers, Dr. John Hays Hammond.

ADDRESS OF JOHN HAYS HAMMOND, PRESIDENT OF THE AMERICAN INSTITUTE OF MINING ENGINEERS

MR. PRESIDENT, LADIES, AND GENTLEMEN

This is unquestionably the era of the engineer the world over, and especially is this true of America. To the skill of her engineers in the exploitation of her unparalleled resources America owes her recognized preëminence in the industrial world.

In the development of new fields for industry, the engineer has played a conspicuous part. First comes the mining engineer, the pioneer of civilization, penetrating the dense jungles of the tropics and traversing the ever-frozen North in the quest for gold. His indomitable pluck, his indefatigable energy and his professional skill have sometimes resulted in the discovery of a new territory for human activity and have sometimes, alas! availed naught to save the adding of his name to the already long list of victims of disease or of murderous savages. Closely following the adventurous mining engineer have come in turn, the civil, the mechanical, and the electrical engineers to contribute their labors to the sum of achievements in the advancement of civilization. While the mining engineer has been the pioneer, he recognizes the indispensable coöperation of his confrères and the fraternal congratulation of their common success in this intellectual team-work, through which lost motion is prevented and the highest results are obtained. He rejoices with them in the wise provision of the generous donor of this, our Engineers' Building. This building becomes a clearing house of engineering information, facilitating, as it does, the interchange of professional knowledge through the trinity library and through the personal intercourse of engineers of several specialties; and if we avail ourselves, as we undoubtedly shall, of the opportunities thus afforded to us, we shall contribute in a large measure to the renown of our profession, to the benefit of mankind in general, and to the acknowledgment of our debt to our benefactor, Andrew Carnegie.

MR. LIEB The gift by Mr. Carnegie was made to the three Founder Societies, and to the Engineers' Club, which thereby became our co-partner in the joint enterprise. It is, therefore, proper that we should call upon our partner, bound to us by ties of friendship and of neighborliness—we have let them in on the ground floor—and we are bound to them by a still higher tie connecting the two buildings at the seventh story. I am glad to call upon Mr. T. C. Martin, President of The Engineers Club.

GREETINGS FROM THE ENGINEERS CLUB, BY T. C. MARTIN

To our fellow engineers, who've been looking for many years
Uptown and down, for a home whose rental wasn't high;
We members of the Club which has also felt that rub,
Bring greetings from our Little House nearby.

With you we share the gift; with yours, our voices lift
In praises of Carnegie who aimed our kindred fates to tie.
"A home for you all" is graven on your wall,
And, deeper, on the cosy Little Club nearby.

Here may brethren dwell in peace; here may your tribes increase;
Here may the founts of knowledge ne'er run dry.
But for leisure moments sunny or refreshing milk and honey,
Come over to the kindly Little House nearby.

When weary of the jargon of 4 Pi and of argon,
And of engineering problems that daily multiply;
Just step across the alley, or by the high bridge sally
To the solace of the cheery Little Club nearby.

You are Mining or Electrical, Railway or Mechanical,
All for truth and fact and data in full cry;
But in the Club we're human, not forgetting there is woman,
And *all* are welcome in the Little House nearby.

To us within these walls, to all Fair Science calls,
Onward and upward as our temples pierce the sky!
So, to your flow of soul, we shall pledge a brimming bowl,
Comrades! playmates! in the Little Club nearby.

MR. LIEB It has always been one of the features of the social side of life our professonial engineering bodies that they have fraternized, not only among themselves, but that they have extended their hands across the seas to their brother in foreign lands. We have had numerous interchanges of visits, and it is always a welcome occasion that brings anew the opportunity of seeing our friends from abroad.

Among the distinguished guests that we have with us today is an old friend of many of the United Engineering Society members, who is the official delegate and the special representative of the Institution of Electrical Engineers of Great Britain, Sir William Henry Preece, whom I have the honor to present.

ADDRESS OF SIR WILLIAM HENRY PREECE

MR. CHAIRMAN, LADIES AND GENTLEMEN

It is an old Latin proverb which says *"Poëta nascitur, non fit,"* which is, roughly translated, "Poets are born, not made."

We have had before us just now an unknown poet, and I must say I think that we shall all agree that he must have been born so, for his natural tendency in the matter of fact business that he is engaged in is not one that would aid him in pouring forth such a beautiful welcome in such charming words.

I am here as an engineer who believes in facts; I was not born a poet, and it is my duty as the representative of the British Institution of Electrical Engineers to express for them the great pleasure we have in supporting the new movement that has taken place here—or rather in taking part in the exercises which are culminated in this meeting today.

I think that my friends at home must have been afraid of my being tempted elsewhere during this week, for they have sent me a message to remind me of what my duty ought to be. I received this morning a message which says:

> The President and Council of the Institution of Electrical Engineers send most cordial greetings to the sister institute on the occasion of the dedication of their new home.

I would say, speaking as a member of that Institution, that it gives me the greatest pleasure to be here; and I can say on my own behalf, that I appear here not only as the representative of the English Institution of Electrical Engineers, but also, as you will see by this badge, as a member of the American Institute of Electrical Engineers. In fact, I hold a unique position. It is a kind of duplex position, for there are only two honorary members—one is Lord Kelvin, and the other is W. H. Preece. And I am about to say, there is no honor that I hold higher than the position of honorary member of your Institute.

I felt strongly inclined when Dr. Hutton referred to the functions of the Engineering Societies to say to him that if one wants to know

a little something of the history of the mechanical engineer he should study his Bible, for there he will find in one of the earlier chapters of Genesis that, according to the authorized version, "Tubal Cain was an instructor to all those who worked in brass and iron." There we learn that in very early days, there was something like technical education. That version has been revised in the new edition, and it says "Tubal Cain was a forger of cutting instruments in brass and iron." I hope that Mr. Hadfield, who represents the great industry of cutting tools in Sheffield, will take back home with him this fact that I have found for him, if he did not know it before, in a very old book which I am glad to say many of us read as often as we possibly can.

Sir, I do not know the time that you are going to allot to your speakers, but I can say this, to anybody here who is anxious to hear me on these points: I am such a crank in speaking about what engineering has done, and what engineering is that I can go on as long as tomorrow morning. But I know there are many to follow me, and I will say at once that it is with earnest feelings of pleasure and delight that I come to take part in the proceedings of your Societies; and I say more, that as an electrician I know from the energy that there is in electricity there is always some spirit of some kind that produces attraction by contact, not only with excited objects, but with active spirits, such as I find in this country, and nothing gives me so much pleasure as to come across the Atlantic, for I find that I can go back home with splendid charges of electricity, and charged with energy such as we do not know at home until we have been over here. I am impressed always with the advances made; and I am glad to think I have had the opportunity, and I hope I shall again, to impress upon my fellow countrymen the knowledge, the progress, and the advantages of coming across the ocean to see you.

MR. LIEB We all of us glory in institutions of learning; in colleges, in technical schools, and last but not least, in our great universities. I have the pleasure now of calling upon Mr. Walter C. Kerr, Trustee of Cornell, to say a word on behalf of American universities.

ADDRESS OF WALTER C. KERR

MR. PRESIDENT, LADIES, AND GENTLEMEN

The universities of this country take great pleasure in welcoming this unique postgraduate institution. Just as universities are composed of colleges, each of which represents some phase of learning, so

this institution as here founded is composed of the segregated, yet in many ways united, societies which represent specialized departments of engineering knowledge and performance.

The opportunities and the necessities of universities and of an association of this type are very similar. Philanthropy may found either of them, but what they become is almost wholly guided by what is done by those who operate, conduct and attend. Universities as far as we know, are conducted by a corps of salaried professors and attended by tuition paying students. A university of this type is typified by this building manned by quite a large unsalaried faculty. It may be that it is a tendency toward universal peace, but we have among our students here a vast army, perhaps sixteen thousand of them, who pay their tuition in something better than coin. There is much similarity between universities and an institution of this sort. When Mr. Carnegie created this institution, typified as it is by a building, and composed of these societies, every dollar that went into this—I scarcely know what to call it, but I will say this aggregation, brought a value of one hundred cents in cash; in addition to that, every dollar brought a potential value which is measured by the power that earned it, of a different value from hundred cents. That is the kind of value that makes a million dollars potent for good. It is the power of aggregation into something that is big enough to do good for something. That was given to this aggregation.

With the money value and the potential value there came also another, which may be called a sentimental value, but which is really an inspiration value that is manifold.

This institution is founded to make more effective the activity of men who do things, and it is very appropriate that it should have been done by a man the glory of whose life is a history of vast accomplishment.

A university stands for something which I have not time to define, but it may be stated in one word—Spirit. So many regard the university as a thing that they can make a photograph of, or as a library, or a piece of architecture; of this movement which has taken place in the world, as a building; but beyond and above that is the spirit—a spirit which is coming into activity in this coöperative age. I could expand on that for some time if I had the chance. Suffice it to say that all this being now done, it is "up to us," as it is to the universities to make good that spirit, and when we have under our roof many organizations, and many kinds of men, and some purposes that are identical, and some that are dissimilar, it behooves us all, in the

true spirit which many have already learned at the university, to let that spirit be sounded, we might say, in a desire for universal prosperity absolutely devoid of jealousy.

MR. LIEB I now have pleasure in calling upon another of the special delegates from abroad to these dedication exercises, the delegate from the Iron and Steel Institute of Great Britain, and its president, Mr. R. A. Hadfield.

ADDRESS OF R. A. HADFIELD, PRESIDENT OF THE IRON AND STEEL INSTITUTE

MR. CHAIRMAN, LADIES, AND GENTLEMEN

I very much regretted being unable to be with you yesterday at the memorable gathering which you had, but our steamship was late, although great efforts were made to get us here in time. Still it is with none the less pleasure that I have come today representing that cosmopolitan body, the Iron and Steel Institute, and on their behalf I beg to offer greetings to the United Engineering Society and most hearty congratulations upon the completion and dedication of this superb home.

I had the pleasure of going through the building this morning, and congratulate you upon all the facilities that you have now at your disposal. It is difficult to find a proper adjective to describe all the advantages that you have here, and I can only say that they are indeed superb.

A unique occasion such as this demands more than ordinary congratulation. This I know you have from all engineering and technical societies. The British Institute of Civil Engineers, the past president of whom I am pleased to see here this afternoon, and the Mechanical Engineers of Great Britain, with their 15,000 members, are very glad to add their good wishes to the address which I now have the honor to present, sir, on behalf of my Institute, the Iron and Steel Institute.

Mr. Hadfield here presented to the Chairman an illuminated address bearing the following inscription.

TO THE TRUSTEES OF THE UNITED ENGINEERING SOCIETIES

We, the President, Council and Members of the Iron and Steel Institute desire, on the occasion of the dedication of the building given by Mr. Andrew Carnegie as a home for American Engineering Societies, to offer our sincere congratulations to The American Institute of Electrical Engineers, The American Society of Mechanical Engineers, and The American Institute of Mining Engineers on the

splendid facilities afforded for carrying on their useful work, and feel confident that in their new new and stately home their future will be more brilliant even than their past.

We take this opportunity to express the hope that the cordial spirit of coöperation which has so long animated the members of our Societies may continue, and thus promote industrial progress, the advancement of science, and the extension of technical knowledge.

Sealed with the Seal of the Iron and Steel Institute at 28 Victoria Street, London, this eighth day of April, 1907, in the presence of

R. A. HADFIELD, *President*
BENNETT H. BROUGH, *Secretary*

I desire to thank you once more in person for the great honor you conferred upon me last year in electing me an Honorary Member of your great Institute. There is nothing I prize more highly than that honor.

Gentlemen, I wish you every prosperity in your new home. You have the heartfelt wishes of every British technical man that this home may do the good work which its founder had in view.

MR. LIEB On behalf of the Engineering Societies, I beg to thank Mr. Hadfield and through him the Iron and Steel Institute for this beautiful greeting.

I will now call upon another of the special delegates, the representative of Der Verband Deutscher Electrotechniker.

ADDRESS OF DR. FREDERICK EICHBERG

MR. CHAIRMAN, LADIES, AND GENTLEMEN

I have the high honor of submitting the kind regards and heartiest congratulation of Der Verband Deutscher Electrotechniker. We are delighted to think that you will find a suitable home in this magnificent building. The structure itself is a significant omen for the future not only of American engineers but for engineers all over the world.

The relations between the electro technical mechanics on both sides of the Atlantic are very close, so that the European electro technical mechanic feels at home in America, as does the American in Europe. We have no home for engineers in Europe, where conditions are so different, that could be compared with this building.

The Verband Deutscher Electrotechniker congratulates you heartily on this magnificent new home.

MR. LIEB: Among the special delegates to these exercises, we have the official representative of the Société des Ingenieurs Civils

de France, Mr. Julio F. Sorżano, and he hands me a message which he has received from his Society, which reads as follows:

Please express to the United Society of American Engineers our warmest congratulations on the occasion of the inauguration of their home, and tender to them our best wishes for continued prosperity.

It had been our earnest wish to have with us today President George H. Benzenberg, of the American Society of Civil Engineers. He has been unavoidably detained and cannot be with us, but he has sent us a letter which will be read by Mr. John F. Wallace, past president of the American Society of Civil Engineers.

ADDRESS OF JOHN FINDLAY WALLACE

MR. CHAIRMAN, LADIES AND ENGINEERING BRETHREN

It gives me great pleasure as well as honor upon this happy occasion to be the bearer of the well wishes and kind greetings of the President of The American Society of Civil Engineers, which are contained in the following letter:

CINCINNATI, O., *April 13, 1907*

TO THE EXECUTIVE COMMITTEE OF DEDICATION OF BUILDING OF ENGINEERING SOCIETIES, NEW YORK

In reply to your very kind invitation to be present at the Dedication Exercises on April 16 and 17, of the Building presented by Mr. Andrew Carnegie, I wish to thank you most sincerely and to state that nothing would give me greater pleasure than to be present at this happy and auspicious event, and in person present my most earnest congratulations to the Engineering Societies and to all their members, but engagements which I cannot postpone, prevent me from availing myself of this opportunity to do so.

Though not a member of either of your Societies, I would like to have joined with you in giving hearty expression and acknowledgment of the splendid and generous recognition which Mr. Carnegie has given to American engineers by this magnificent gift. This recognition of the achievements of the profession should stimulate and inspire every one of us to a higher accomplishment and to nobler purposes so that the lofty motive which actuated the donor when he formulated his proposal may have its warrant in the further progress made by the engineer in every branch of his profession, between which no envy or rivalry should ever exist, excepting that contention of the engineering profession in every branch for the benefit of the profession at large.

May this Home be a monument to the eminence and standing which the engineer has attained in every branch of the great industrial advancement of this country, and may his further progress and success in the economical development of the resources of nature for the use and benefit of man bring to him the full recognition he shall deserve.

Please accept and convey my sincerest good wishes and congratulations to the

Societies upon this occasion of the memorable opening of their new Home, and may the spirit of peace, progress, and prosperity ever dwell within its walls.

With kindest regards, I remain,

Very truly yours,

G. H. BENEZENBERG,

President, The American Society of Civil Engineers.

I desire to embrace this opportunity to endorse the sentiments contained in this letter, and also to congratulate both the donor and recipients of this magnificent building upon the spirit upon which it was given and received. May it bear abundant fruit in the years to come in perfecting the bonds of friendship and coöperation among all members of the engineering profession.

MR. LIEB I will now call upon a representative of the technical institutions of learning. I have the honor to present Dr. Henry Pritchett, President of the Carnegie Foundation.

ADDRESS BY HENRY PRITCHETT, PRESIDENT OF THE CARNEGIE FOUNDATION

MR. CHAIRMAN, LADIES, AND GENTLEMEN

I bring to you the greetings from the Institute of Technology and from its sister institution which I hope may be none the less cordial and none the less hearty because they must be brief.

We who labor in the preparation of men for the calling of the engineer have felt a keen interest in your success and in your gift, I think, for two reasons mainly: one because we have seen here an effort toward coöperation and unity, and we feel that that progress is in accord with the spirit of the age. There could be no more fitting time to dedicate such a building as this, occupied and to be held by the United Societies, than at the time of the meeting of a great peace Conference. Secondly, we feel a great interest in this evidence of prosperity of the part of your societies because it is a recognition of the dignity and of the value of the calling of the engineer. After all, the engineer is the real civilizer of today; is the real advance agent of civilization and of culture; and I cannot but think that such a building of engineering could have been given no more fittingly by any one than by a man born in Scotland because Scotland was civilized by the engineers. There is a tradition that it was done by the poet and by the priest and by the university, but as a matter of fact it was done by the engineers. The story is a short one. At the end of the eighteenth century the inhabitants of Scotland were still engaged in the noble business of lifting cattle from their southern neighbors. I have

no doubt that the Carnegie clan got its full share. They had poets, they had prophets, they had universities, but they lacked civilization. Four engineers came along and civilized them. One taught them how to build roads, and his name is perpetuated today in the street pavement known as the Telford. The second taught them how to build a bridge across a stream. A third, and perhaps he was the greatest of all, taught them how to harness the power of steam. The fourth taught them how to draw on two rails with steam power a wagon. Those four men did in fifty years more than all the poets and prophets and universities had not done in a thousand years; they changed the country from a generation of cattle lifters to a generation of civilized men.

Speaking in all seriousness, sir, this building is of greatest moment to us because it does recognize that very fact. Your engineer is today the real worker in civilization. He is not a poet, he is not a prophet, he is not a priest; but he is a constructor. He represents the constructive side of human development—not the destructive side or the passive side, and as such he is the real maker of the civilization of our day.

What is it that makes civilization? What is it that civilized Scotland? It was the making of transportation, it was the bringing of men together, for it is not weakness that brings war and that makes peace impossible, but it is the ignorance, the lack of knowledge of one people of another that makes war possible and that brings with it all the horrors which war entails, and he who builds the railroad, he who throws a bridge across a stream, he who makes transportation possible, is the man who builds the enduring paths of peace and of civilization.

So we, sirs, of the technical school, ask you as engineers that you may help us in our work of instruction to realize and to make our students realize that the engineer is the builder not only of material civilization, but that he must be in this next quarter century a builder also of those structures which look toward things which are spiritual and toward things which are eternal.

MR. LIEB I will now call upon the representative of the Verein Deutscher Eisenhüttenleute.

ADDRESS OF MR. CHARLES KIRCHHOFF

MR. CHAIRMAN, LADIES' AND GENTLEMEN

I come to you today to bring the greetings of one of our German sister societies whose headquarters are in that beautiful city on the

Rhine, Düsseldorff, where they have cunningly succeeded in establishing both an art center and an industrial center. Visits have been exchanged repeatedly between the Verein Deutscher Eisenhüttenleute and the societies on this side of the water, and speaking as a guest on those occasions I can assure you that if I should be a host in future years you will find true again what you have found in the past. There is an open hand, an open heart, and an open cellar door ready for you at all times.

I do not want to take up your time, but I have to present in behalf of the Verein Deutscher Eisenhüttenleute an illuminated address, and I will confine myself to the simple reading of the words upon it:

TO THE UNITED ENGINEERING SOCIETIES

The President, Council and Members of the Verein Deutscher Eisenhüttenleute beg to convey their most cordial wishes for the prosperity of the home of the kindred American Engineering Societies.

This is signed by the President, Dr. Springorum and by Dr. Schrödter, the Secretary, and it bears a casting which makes the letters "Glueck Auf," that most charming of all greetings which is untranslatable but which possibly we get nearest to when we say "good luck."

MR. LIEB Many of us in our visits abroad have had the opportunity of enjoying the warm hospitality of our French confrères, and it is with great pleasure that we have officially with us today the Société Internationale des Electriciens, represented by Mr. Carl Hering.

ADDRESS OF CARL HERING

MR. CHAIRMAN, LADIES AND GENTLEMEN

The Société Internationale des Electriciens of Paris sends its most cordial greetings to the United Engineering Society and extends its hearty congratulations on the occasion of the acquirement of this magnificent and palatial home.

The society which I have the honor to represent today is to France what the American Institute of Electrical Engineers is to America. Each is a national society of electrical engineers fundamentally, and they are, therefore, sister societies in the truest sense of the word, their work and interest being on similar and parallel lines and in nowise competitive. The spirit of brotherly friendship between them is a true one. Such occasions as the present, which bring us closer together and increase our friendship, are therefore highly prized. Our more intimate relations began in the year 1900, when the Ameri-

can Institute of Electrical Engineers made its first visit to its French sister and held a joint meeting with it and the British sister societies in the city of Paris. This I believe was the first meeting that you ever held in any foreign country, and the honor that your first official visit abroad was to our society is highly appreciated. We very much enjoyed your visit the year following, and the hospitality you extended to us on that occasion will long be remembered by us and has drawn the bonds of our friendship still closer. We cherish the hope that these more intimate relations so happily begun will continue, and that you will let our home be your home when you visit Paris again. Although we are not the fortunate possessors of such a magnificent home as the munificence and generosity of the donor of this building, the distinguished and philanthropic citizen not only of America but I may say of the world, Mr. Carnegie, has given you, your welcome will be no less sincere. May your prosperity be as great as your new home is palatial.

MR. LIEB I will now call upon the Faraday Society of Great Britain, represented here by its special delegate, Mr. Leon Gaster.

ADDRESS OF MR. LEON GASTER

MR. PRESIDENT, LADIES, AND GENTLEMEN

I think it is not becoming for a young man, and perhaps the youngest institution, to take up much of your time, but I wish to tell you that this is my first visit to this country and to express to you our heartiest congratulations and assure you that the impressions which I have gained on this occasion I shall hope to carry back to my colleagues and tell them that one thing is certain: You have a very broad platform of work, and our society, as it happens, electrochemical, mixes with electrical and mining engineers. Therefore we will very gladly look forward to this center of light and assure you that it will be always a great pleasure to remember the opportunity that has been afforded me to see how in this country science is international and knows no boundaries, and moreover professional jealousy is trying to be as much as possible eliminated, all working for one common aim; and I am perfectly satisfied that Mr. Carnegie and I am sorry to say that there are not more men like him who will spend their money in their lifetime and do good with it—will realize his hope of unity and coöperation, and I hope that he will live a good long while to see in his old days the good he has done and how he has inaugurated an idea which will be a leader for other nations to follow.

MR. LIEB We had expected to have with us today the President of the Canadian Society of Civil Engineers W. McLea Wellbank. He was unavoidably detained, but he sends us this telegram:

Unavoidably prevented from being with you tomorrow. Please convey to the meeting our sincere congratulations.

MR. LIEB We also have greetings from the Associazione Elettrotecnica Italiana and Societá degli Ingegneri ed Architetti Italiani, whom your Chairman has the honor to represent.

On behalf of the Associazione Elettrotecnica Italiana and the Italian Society of Engineers and Architects, I have the honor to extend to the Engineering Societies fraternal salutations and felicitations from their Sister Engineering Societies in Italy on the auspicious occasion which you are now celebrating.

Italy, the country of Leonardo da Vinci, of Michael Angelo, of Bramante, of Giotto, Galvani, Volta, Ferraris and Marconi. extends to her younger sister Columbia her warm congratulations on the splendid monument to Engineering Science which the generosity of one of her sons has enabled American Engineers to erect.

That our American Brethren may continue to carry forward the banner of progress, growing in numbers, industrial achievements and influence, is the sincere wish of their professional colleagues in Italy.

I will now call upon Dr. F. S. Archenhold, Direktor der Treptow Sternwarte.

MR. PRESIDENT, LADIES AND GENTLEMEN

I regard it as a special honor to bring the greetings of the Treptow Observatory and to take part at the opening festivities of the United Engineers Society.

You will pardon me, if I, a German, should not be able to express everything as I feel it. We astronomers know very well how to appreciate the work of the skilled mechanics and engineers. Our modern telescopes have reached dimensions so that their construction and especially their movements demand the highest degree of accuracy, and their construction has become so complicated that only the combined work of the various engineers are able to solve this task satisfactorily

Machine engineers, fine mechanics, and electricians must combine to secure the stability and movability of the iron giant.

A mammoth telescope has been built at Treptow, near Berlin, the objective of which has a diameter of 28 inches and a length of 70 feet. It was constructed by skilled engineers after my own plan.

I take the liberty to present to the President of the United Engineering Society a picture of this telescope, which instead of the usual dome, has a protecting cylinder and its center of gravity coincides with the turning point and the viewing point.

The observer stands, so to speak, in the center of the cosmos. Furthermore, I will donate to the United Engineering Society the last volume and the current one of "Das Weltall," a scientific periodical, of which I am the editor. You will find

in them among others the illustrations of the sun spots which I have made by the aid of this telescope. These illustrations show how large the image of the spots appear in this telescope, as they are represented in the orginal size.

That I am here in this assembly, I attribute to the kindness of the gentleman whom the Observatory of Treptow esteems highly as an honorary member—Mr. Carnegie.

Since I have reached American soil I have met with his generosity and his ideals in admirable institutions, libraries, and homes for arts and science. What I have seen in Pittsburg as the guest of Mr. Carnegie is what I had always in mind as my ideal in Germany, and this unique man has realized it. The building of the Engineering Societies has impressed me as being exceedingly serviceable to its purpose, and everything is so beautiful that I feel it must be a real pleasure to be a member of one of the societies who call this building their home.

We cannot be grateful enough to this man, who has built a palace for the engineers, which better than words expresses how our modern times appreciates their work.

As our most eminent astronomer has reached his highest goal but through the liberality of the ever remembered Danish King, so the growing success of the American engineering science will ever be connected with the immortal name of the great steel-prince, Andrew Carnegie.

MR. LIEB We express our cordial appreciation to Dr. Archenhold for his gifts.

I will now call upon a representative of one of the Associate Societies, who are coöccupants of the building with us: the Society of Naval Engineers, represented by its President, Captain Baxter, U. S. N.

ADDRESS BY CAPTAIN BAXTER, U. S. N.

MR. CHAIRMAN, LADIES, AND GENTLEMEN

Those of us who belong to these kindred societies consider ourselves brethren of the Founder Societies. Our Founder Societies have grown; they are large, they are strong, they are wealthy; but still we are of the same family. We belong individually one to another. In all of our different relations we work as individual societies, but I believe firmly that it is right that these smaller societies should exist because they develop the special work which is called for in certain special lines. It is true that that work could be developed in sections, the same as in a large university, but our American idea is not on that line. We get together and talk about this thing or that thing in a corner, the other thing in the other corner, and, while we do that we are thinking of that and of nothing else because that is our individual work. If we do not develop the particular kind of thought which belongs to our individual corner, we

do not do our duty as engineers. We may be a small body, or we may be a section. That is a matter of detail to be settled in the future.

In the meantime, I wish to say that the Associated Societies feel very deeply the kindness and the courtesy which they have experienced from the Founder Societies, and that they will coöperate with them in every way. Coöperation, from what we heard yesterday, is "the thing" in engineering.

The particular society that I am fortunate enough to represent, according to what we have seen should be rechristened and should be called the Society of Ship Engineers, because that will embrace every kind of engineering that ever did exist and ever will exist.

I wish the Founder Societies to feel that our small societies appreciate the work which you have done and also wish you to feel that our work, good or bad, is absolutely at your disposal. We are all brothers, and as brothers we are all together. A small boy was reprimanded by his mother for his quarrelsome act in some little thing, and after she had explained the trouble to him and he was feeling very badly and realized that he must do better in the future he ended by saying: "But, mother dear, anyhow we are all *us*."

MR. LIEB I hold in my hand a large number of congratulatory letters and telegrams, all of which it would be impossible to read, but some of them should certainly be brought before you, and with your permission I will read some of them.

LONDON, *April 4, 1907*

I am sorry it is not possible for me to be present on the occasion of the dedication of the building of the Engineering Societies on April 16 and 17, as I must be in London at that time.

(Signed) KELVIN.

The Institution of Civil Engineers, Great Britain. Under a resolution of the Council I have the honor to request you to convey to the Trustees of the United Engineering Society the very warm congratulations of this Institution upon the occasion of the dedication of the new building established as a home for American engineering societies. With an expression of the hope that it may be the means of furthering the interest of the engineering profession and of establishing more closely the relations which exist between its various branches, I have the honor to be, sir, your obedient servant,

J. H. T. TUDSBERY, *Secretary.*

The Council of The Institution of Mining and Metallurgy now assembled send cordial congratulations to American confrères on the dedication of the Engineering Societies building.

We also have a letter from the Directeur du Conservatoire National

des Arts et Mètiers, Paris, in which he conveys cordial greetings to the Engineering Societies on this auspicious occasion.

SEVRES, *April 6, 1907*

International Bureau of Weights and Measures is very happy to express their sincere joy that through the liberality of Mr. Andrew Carnegie the Engineering Societies of the United States will possess from henceforth a home worthy of them.

We also have a cablegram from Berlin reading as follows:

On the occasion of your entrance into the new home, the Society of Marine Architects sends congratulations.

CHAIRMAN LIEB We have today as one of the features of our program the presentation of the John Fritz Gold Medal, and as an introduction to the presentation of that medal I will ask Mr. Fritz to kindly step to the platform.

(Mr. Fritz stepped upon the platform admidst great applause.)

This medal, as you know, was founded by a number of friends, and he has a host of them in the engineering profession, of our honored colleague, John Fritz.

The American Society of Civil Engineers, The American Society of Mechanical Engineers, The American Institute of Mining Engineers and The American Institute of Electrical Engineers, through their representatives, organized as a Board of Award to confer this medal. Mr. Charles F. Scott is the chairman of the board which has awarded the medal this year to Dr. Alexander Graham Bell.

ADDRESS OF CHARLES F. SCOTT IN AWARDING MEDAL TO ALEXANDER GRAHAM BELL

The announcement of the award of the John Fritz medal at this time and on this occasion has a peculiar significance, for this building owes much to the John Fritz medal. The coöperative movement by which the International Engineering Societies joined in founding the medal was inaugurated in the latter part of October, 1902, at a dinner given on that date, and it did much to develop the sentiment of which this building is the outcome. I am very glad myself to acknowledge that it is to that dinner that I owe the beginning of an acquaintance with the engineering societies and had a glimpse of what they might accomplish by working together, which has been the motive which has guided me in my relations to the development of the enterprise which had its outcome in the completion of this building.

The vision of the future which we seemed to see in a reflection of the John Fritz medal, a larger life for the engineer of the twentieth century, was discerned by a genius in foreseeing the future and in devising means for the uplifting of man, and with the magic touch of his wand of wealth he has transformed that vision into a magnificent building as a capitol for American engineers.

The John Fritz medal is more than a bit of gold; it is more than honor to a man for his notable achievements. It represents a sentiment, an ideal, an actuating force from which has come, as one of the first proofs which he has contributed, this building.

Three awards of the John Fritz medal have been made by the board of award constituted of representatives from the four National Engineering Societies. The first award, in 1905, was to Lord Kelvin, for his work in telegraphy and other scientific achievements. The second award was in 1906 to George Westinghouse for his invention and development of the air brake. The third award was made in January, 1907 to Dr. Alexander Graham Bell.

(Here Mr. Scott turned and addressed Dr. Bell.)

On behalf of the board of award of the John Fritz Medal I have the honor to present to you this medal for the invention and introduction of the te'ephone.

Response of Alexander Graham Bell

Mr. Chairman, Ladies, and Gentlemen

I hardly know how to express myself fittingly in response to the honor that is bestowed upon me. I can only say that I appreciate very highly this medal, and I shall prize it also from the fact of its being presented in this magnificent building, this temple dedicated to applied science, the home of the United Society of Engineers, but I think what will give this medal greater force in my recollection will be the fact that it is presented in the presence of the venerable John Fritz himself.

Chairman Lieb It may interest many of the friends of Professor Bell to learn at this time that he sails on Friday for England to receive the degree of Doctor of Science from Oxford University, a rare and distinguished honor.

As has already been stated today, the Engineering Societies have for many years conducted their work under extraordinary difficulties in unsatisfactory and inadequate quarters. That the Engineering Societies under such disadvantages did nevertheless thrive and grow

in number and influence, is due largely to the work of their indefatigable secretaries. In undertaking to choose whom I should first introduce in connection with the presentation of the medal which is to be hereafter entitled "Distinguished Services Medal," my first inquiry was as to their relative length of service, and when I say to you that two of them had 23 years' service, and one 22, I do not think we can make any distinction on that account. I therefore call upon Dr. A. R. Ledoux, Past President of the American Institute of Mining Engineers, representing the three Founder Societies, to present these medals.

Address of Dr. Albert R. Ledoux

Mr. Chairman and Gentlemen of the Founder Societies

My share in these exercises is most pleasant. It is in your name to tell three men how much they are appreciated by you.

There is a saying that republics are ungrateful. The same is sometimes affirmed of "souless" corporations. But this cannot be charged against our three Societies. The *dominant* note of these exercises has been gratitude for this splendid home, in which we will dwell together in fraternal unity, and there are still other notes of gratitude that we would sound today.

In every organization, whether the individual units are represented by trustees, or directors, or committees, there is always some one man who does the greater part of the work. With us, it has been the Secretary. Presidents come and go, but the Secretary works on unceasingly.

We have been most fortunate in our three Secretaries, not only on account of their executive ability; not only on account of their tactfulness and other qualifications of mind and heart; but on account of their unselfish willingness to devote so many of the best years of their lives to our several interests. During their official incumbency, we have developed from small beginnings into the splendid aggregation of nearly 12,000 members. Whatever may be the achievements of their successors in office, these men have set a standard which it will be difficult for anyone to surpass.

The American Institute of Electrical Engineers was organized in 1884. In 1885, Ralph Wainwright Pope was elected its Secretary. Born August 16, 1844, educated at Great Barrington and at Amherst College, he developed early in his career a marked taste for mechanics, and has been continuously identified with what might be called applied electricity. He entered the service of the Housatonic Railroad in 1859. At the outbreak of the Civil war, like other men,

whose names and work have recently been recalled with especial honor, he entered the service of the United States Government as expert telegrapher. Then he was connected with the American Telegraph Company, and the New York and New Haven Railroad; and later with the famous Collins Overland Telegraph Expedition, which the success of the Atlantic Cable prevented from establishing connection with Europe across the wilds of British Columbia, Alaska, and Siberia. Mr. Pope was for ten years subsequently in the service of the Gold and Stock Telegraph Company, resigning the position of Deputy Superintendent in 1883. From that date until 1888, he was actively engaged in the editing and publishing of technical electrical papers in this city. He was the organizer of the Telegraphers' Protective League, and the Gold and Stock Life Insurance Association, and is a member of the New York Electrical Society and Honorary Member of the Franklin Institute.

But it is of his service as Secretary that I speak with especial emphasis. In 1887, he consented to devote practically all of his time to the Institute alone. He has made a constant study of its needs and has not hesitated to recommend the adoption of all that appealed to him as desirable in the methods and activities of other technical organizations.

Perhaps the best evidence of the appreciation of Mr. Pope's service is that furnished by the members of the Institute itself. The office of Secretary is purely elective, and the term is only one year. Mr. Pope has been reëlected 22 times without opposition.

His clear conception of details; his genius for taking pains; and the orderly methods of his office, have earned for him the affection and the gratitude of the Directors and Members of the American Institute of Electrical Engineers whose wishes he has so ably carried out.

Long may it be said of our Secretaries that none dies! But it can no longer be said that none ever resigns, for the record of the trio, whom today we honor, has just been broken by the election (I do not say promotion) of Secretary Frederick Remsen Hutton to the Presidency of the American Society of Mechanical Engineers.

Dr. Hutton was born in this city on May 23, 1853, graduated from Columbia University in 1873 as A.B., received the degrees of M.E. in 1876, Ph.D. in 1882, and Sc.D in 1904. Since his graduation and up to the present time, Dr. Hutton has been intimately connected with the life and growth of his *alma mater*. He was, as instructor in mechanical engineering, associated with the late Prof. W. P. Trowbridge; was appointed adjunct Professor in 1881, and

full Professor in 1890, and was Dean of the Faculty of Applied Science for many years.

Perhaps Professor Hutton has left his most enduring mark upon Columbia University through his successful efforts to create and equip one of the most complete mechanical laboratories possessed by any of our technical schools. He has found time in the midst of many exacting duties, not only to devote his abilities to the building up of the Society of Mechanical Engineers, but to many outside activities. He has been school trustee, editor of the Engineering Magazine; one of the editors of Johnson's Encyclopedia, the Century Dictionary, etc., the author of works on mechanical engineering, power plants, heat engines, machinist tools, the gas engine, etc., etc. Like Mr. Pope, President Hutton has rounded out almost a quarter of a century in the office of Secretary of his Society, for he was elected to that office in 1883, and annually ever since until he declined a reëlection in 1907.

Members of this Society assure me that its growth has been largely due to the energy and optimism of its Secretary. Through his initiative, some of the valuable additions to its library were acquired. It was partly his courage that made it possible to purchase the headquarters building in West Thirty-first Street, the recent sale of which at double the cost price confirms the wisdom of the venture.

During the last three years, another burden has been placed upon the shoulders of Dr. Hutton, for he has also been the Secretary and one of the most active members of that unique body of allied engineers, known as the Trustees of United Engineering Society, and of the Joint Building Committee, charged with the designing, erection, and maintenance of the edifice in which we are assembled today. Would that I could in adequate terms express appreciation of the symmetry and order which he has maintained in the proceedings and records of all of these organizations, and in this I can speak with knowledge, for until 1906 I had the honor to be President of the United Engineering Society.

I turn now to mention another of our three great Secretaries, Rossiter Worthington Raymond. I have found it difficult, for personal reasons, to confine myself to an enumeration of the *public* services of this veteran officer of the American Institute of Mining Engineers, for my association with him has been very intimate. We have counselled together for the Institute, in dark days and in bright, and for nearly a decade, as occupants of the same building, we came in daily, personal contact. But I must forbear to say what I would of his lovable qualities as a man.

Dr. Raymond was born in Cincinnati on April 27, 1840. After education in public and high schools, he graduated from the Polytechnic Institute of Brooklyn, in 1858, at the head of his class. He was one of the first of our great American Mining Engineers to take advantage of the instruction at the Mining Academy at Freiburg, Saxony, after preceding courses at the universities at Heidelberg and Munich.

Returning to America, in 1861 he enlisted in the union army, resigned in 1864 with the rank of Captain. He was on the staff of Major General Fremont during the campaign in the valley of Virginia. From 1864, Dr. Raymond has practiced as a consulting mining engineer and metallurgist. In 1867, he became the editor of the American Journal of Mining, the predecessor of the Engineering and Mining Journal, in the establishment of which he had a large share, the weight of his pen being one of the contributing factors of its continued success. In 1868, he was appointed United States Commissioner of Mining Statistics, which position he retained until 1876, editing eight monumental reports. He was lecturer in economic geology at Lafayette College, from which he received the honorary degree of Doctor of Philosophy in 1870. From Lehigh University he received the degree of Doctor of Laws in 1906.

The American Institute of Mining Engineers was established in 1871. Dr. Raymond was chosen Vice-President, really discharging the active duties of the President, owing to the physical incapacity of the veteran David Thomas. Dr. Raymond was thrice elected President, and was made Secretary in 1884, since when he has been annually reëlected the executive of the Institute. For years he was sole editor of its Transactions. These Transactions of the Mining Engineers have been the standard, upon which many newer scientific bodies have modeled their publications, and upon which some of the older organizations have remodeled theirs. The products of Dr. Raymond's versatile pen have often adorned these volumes, as well as the pages of many other publications in this and in foreign countries. His essays upon our complex and unfortunate U. S. mining laws and a history of mining law, published by the U. S. Geological Survey, are among the most important of his monographs. In 1903 he delivered a course of lectures on Mining Law, before the advanced students of the School of Mines and the Law School of Columbia University.

Amid all his varied professional duties, Dr. Raymond found time also to devote himself to matters outside of mining and metallurgy. In 1893, he was admitted to the bar of the Supreme Court of the

New York State, and subsequently to the Federal Courts, and has been repeatedly named in judicial decisions as an authority, particularly upon mining and patent law.

In 1885, Dr. Raymond was one of the three state Commissioners of Electrical Subways of the City of Brooklyn, and for four years Secretary. He prepared the final report, which is still quoted as one of the most important contributions to municipal engineering.

Many honorary degrees and honorary elections to important societies have been conferred upon Dr. Raymond, from all parts of the United States and from Europe. For twenty years he was consulting engineer of the New Jersey Iron and Steel Company, the Trenton Iron Company, and other of the mining and metallurgical corporations, controlled by the firm of Cooper and Hewitt.

It is surely not out of place in this presence, to mention briefly the work of Dr. Raymond along still other lines. His articles on "Labor and Law" and "Labor and Liberty," his management of the Saturday Evening Free Popular Lectures at Cooper Instiute, at which he often presided, his discriminating "Life of Peter Cooper," and other writings too numerous to mention have shown his deep grasp of our social problems and his sympathy with his brother man. His name is indissolubly associated with the work and history of Plymouth Church.

In order to give public expression to the appreciation of these three Founder Societies for their three great Secretaries, there have been prepared by the distinguished artist, Victor Brenner, three identical gold medals. Upon one side there is depicted a figure representing the spirit of invention and research, typified by a youth who holds in his hand a tablet, upon which his attention is fixed. Enveloping him is a cloud of steam, which rises from the stack of a modern locomotive, typical of mechanical engineering; above appears the top of a blast furnace. Below and at his right hand appear the emblems of the "Founder Societies" encircled by an olive wreath, while opposite is a view of our present building, with an inscription reciting the fact and date of its dedication. Above the seated figure, are suggestions of the work of the electrician and miner, represented in the one case by a high tension electric line and in the other by men operating a power drill. Upon the obverse of each medal are inscribed the circumstances of its bestowal and the name of its recipient.

And now, Mr. Pope, Prof. Hutton, and Dr. Raymond, I take pleasure in handing to each of you this token of our sincere appreciation and regard. In the name of our three Societies, I thank you for past service, and express the hope that you may long be spared to give

us the benefit of your ripe experiences and the inspiration of your leadership.

Response on Behalf of the Recipients of the Medals by Frederic Remsen Hutton

As the youngest in age, the longest in service and the one no longer in secretarial office my associates have asked me to speak for them.

Upon a Judean hill-side on the first Christmas night 1900 years ago, were craftsmen doing the duty of the hour under the open sky.

They were not remarkable men. They were doing the thing which lay next to them. Suddenly a glory of light burst upon them, and in the silence of amazement they listened to a wondrous message. It was not a message to them alone, but one for all the world. It told of the beginning of an era, to be one of good will and peace.

There have been three craftsmen in the three Societies who for over twenty years have each day been doing the duty of the hour at their office desks.

They have not regarded themselves as remarkable men. They have simply been doing the thing which lay next to them. They have loved their work, but this privilege they share with all whose work is done mainly for others.

Suddenly a blaze of appreciation has burst upon them from their associates, and it has dazzled and confused them. They take it, however, that through these tokens for which they thank you, the givers mean to utter a message, which is not to us alone, but to Engineering at large; that at this time and with the coming of this building begins a new era, which this occasion symbolizes and which is to be one of progress, prosperity, and peace.

Chairman Lieb declared the dedication exercises of the Engineering Societies Building closed.

Congratulatory Messages from Sister Societies and Institutions of Learning

Bruxelles, Belgium, *Avril, 1907*

To the Engineering Societies

I am instructed by our Board as Past President of the Société Belge des Electriciens de Bruxelles to thank you for your kind invitation to be present at the dedication of the new Engineering Societies building in New York.

The wishes of our fellow countrymen are that the three noted American Engineering Societies should develop more and more in their new home the scientific action on general progress for the special benefits and honor of the technical people of United States.

We wish special success to our colleagues of the American Institute of Electrical Engineers whose works and valuable Proceedings are highly appreciated in our country.

Please report this expression of Belgian feelings to our American fellows.

Yours very truly,

LEON GERARD
Past President Société Belge des Electriciens

GRAVENHAGE, THE NETHERLANDS
April 5, 1907

The Board of the Kon'nklijk Instituut van Ingenieurs congratulates the United Engineering Society most heartily upon their new home. May it become the symbol of the fraternity and the cordiality which exists between the scientific engineers of different branches.

HAMPSTEAD, N. W., ENGLAND, *March 30, 1907*

Mr. Spagnoletti presents his compliments and begs to return his sincere thanks for the kind invitation sent him by the Trustees of the Engineering Societies in New York on the occasion of the dedication of the new building on April 16 and 17. He very much regrets his inability to be present on this important occasion.

As "Unity is strength" he trusts all branches of engineering may be strengthened and improved by the close proximity in which they will now be brought together under one roof.

HASLEMERE, ENGLAND, *March 30, 1907*

Sir James Kitson begs to acknowledge and thank the Trustees of the Engineering Societies for their invitation to be present at the dedication of the building given by Mr. Andrew Carnegie to the American Engineering Societies. He greatly regrets that his engagements in England prevents his accepting this invitation. The American Engineering Societies are happy in having so kind and appreciative a friend as the open handed Andrew Carnegie.

PARIS, FRANCE, *April, 1907*

Victor Belugou, Principal Engineer of Posts and Telegraphs, cordially thanks the Trustees of the Engineering Societies for their valued invitation for April 16 and 17, and he regrets very much not to be able to attend the ceremonies.

He sends the expression of his sincere sympathy to his American colleagues, and congratulates them on the magnificent gift which has been presented to them.

PARIS, FRANCE, *April, 1907*

TO THE ENGINEERING SOCIETIES

I thank you very sincerely for your kindness in inviting me to the inauguration of the Palace of Engineers donated by Mr. Andrew Carnegie to the Founder American Societies. It is impossible for me to attend this inauguration, but it is my desire to assure you of my great appreciation of the brotherly sentiments between engineers which has been the starting point of this magnificent donation.

Please accept, dear sir, the expression of my highest esteem.

Yours very truly
H. LE CHATELIER

BERLIN, GERMANY, *April, 1907*

Upon the occasion of the entrance of the Engineering Societies into their new home, the Society of Marine Architects sends congratulations.

THE ROYAL OFFICE FOR EXAMINING MATERIALS
BERLIN, GERMANY, *April 5, 1907*

The Royal Office for Examining Materials begs to express the sincerest thanks for the friendly invitation to the ceremonies of inauguration of the Carnegie building for the American Engineering Societies, and regrets that it is impossible at present to send a representative.

The office begs to send the heartiest congratulations on this auspicious occasion.

Yours very truly,
A. MARTENS

BERLIN, GERMANY, *April 16, 1907*

TO THE ENGINEERING SOCIETIES

We send our hearty greetings to the American Engineering Societies on the occasion of the dedication exercises of their home, and wish them continued success in their activities.

VEREIN-DEUTSCHER INGENIEURE

BERLIN, GERMANY, Genthiner-Strasse 13, Villa C, *April, 1907*

TO THE ENGINEERING SOCIETIES

I am very sorry that I cannot accept the invitation to the dedication of the Engineering Societies Building on April 16 and 17.

Were it possible for me to attend it would give me great pleasure to be present as an honorary member of the American Institute of Mining Engineers and as representative of the Verein zur Beförderung des Gewerbfleisses. I can however only beg to offer my congratulations in these two capacities to the Engineering Societies.

Yours very truly,
H. WEDDING.

ROME, ITALY, *April 16, 1907.*

TO THE ENGINEERING SOCIETIES

Fraternal salutations on the dedication of the great institution now inaugurated.

ASCOLI, *Past President,*
Associazione Elettrotecnica Italiano.

MILAN, ITALY, *April 16, 1907*

TO THE ENGINEERING SOCIETIES

Fraternal Greetings to The American Engineering Societies from the Royal Polytechnic Institute of Milan and myself.

COLOMBO, *Senatore del Regno*

ROME, ITALY, *April 15, 1907*

TO THE ENGINEERING SOCIETIES

The Royal Academy of the Lincei, Rome, expresses to the American Engineering Societies its great satisfaction that the munificence of Andrew Carnegie gives them a glorious home in which to broaden their activities in the rapidly increasing technical and industrial development of your splendid country.

BLASERNA

ASSOCIAZIONE ELETTROTECNICA ITALIANA

MILAN, ITALY, *April 6, 1907*

MR. JOHN W. LIEB, JR., Chairman

Dear Sir: I beg to tender my heartiest congratulations on this exceptionally interesting event to which I wish every success and I am sorry that none of the members of our Council will be able to come over to represent the Associazione Elettrotecnia Italiana.

Under such circumstances I should be very pleased if you kindly would officially represent the Associazione Elettrotecnica Italiana at the ceremony, and tendering my best thanks as well as those of all its members, believe me to remain, dear sir,

Very truly yours,
E. [illegible] A, President.

MILAN, ITALY, *April 5, 1907*

TO THE ENGINEERING SOCIETIES

I feel very much indebted for your very kind attention in sending me a formal invitation to attend personally the Dedicatory Exercises of the new building of your Engineering Societies. I am greatly disappointed that the distance which separates us prevents me from being present at such an important ceremony.

The dedication of this building marks one of the modern triumphs of Engineering of which we can all be proud as it shows how largely the benefits of the profession are appreciated by mankind.

With very best wishes I remain,

Yours very truly,
G. SEMEMZA

ASSOCIAZIONE ELETTROTECNICA ITALIANA

TURIN, ITALY, *April 2, 1907*

TO THE ENGINEERING SOCIETIES

I beg of you to express my regrets to the Committee since the distance makes it impossible to give myself the pleasure of being present, but I assure you I will be there at least in heart.

Recollecting all the kindnesses shown to me and my Italian colleagues by the American Institute of Electrical Engineers, I wish to express the deepest sentiments of gratitude to our American friends. I offer my best wishes for the perfect success of the ceremonies on the occasion when such a great honor will be conferred on electro-mechanics. The Engineering Societies Building stands as a proof of the high civilization of the American nation.

With kind regards, I beg to remain,

Yours very truly,
GUIDO GRASSI

The Founders and Trustees of the Thomas S. Clarkson Memorial School of Technology send greetings and heartiest congratulations to Mr. Carnegie and the Presidents of the Founder Societies upon the opening and dedication of the Engineering Societies Building.

THE COLORADO SCIENTIFIC SOCIETY

DENVER, COLO., *April 15, 1907*

TO THE ENGINEERING SOCIETIES

The Colorado Scientific Society takes great pleasure in extending to the Engineering Societies on this most happy occasion its congratulations on the completion of the new building, and its sincere good wishes for future growth and prosperity.

Most truly yours,

THOS. L. WILKINSON, *President*
W. J. JOHNSTON, *Secretary*

PITTSBURG, PA., *April 10, 1907*

Mr. Emil Swenson regrets exceedingly his inability to be present at the dedication of the building given by Mr. Andrew Carnegie, as a home for American Engineering Societies. Congratulations are tendered the Trustees of the United Engineering Society, with best wishes for the future.

THE WESTERN ASSOCIATION OF TECHNICAL CHEMISTS AND METALLURGISTS

DENVER, COLO., *April 15, 1907*

TO THE ENGINEERING SOCIETIES

The officers and members of the Western Association of Technical Chemists and Metallurgists extend to the Founder Societies their hearty congratulations and best wishes at this dedication of the new building in New York. We are proud of your past and we rejoice with you in your future.

Most sincerely,

W. G. SWART, *President*
H. C. PARMELEE, *Secretary*

ILLUMINATED GREETING

NEW YORK, *Aprl, 1907*

Columbia University tenders warmest congratulations to the Engineers of America upon the occasion of the dedication of their new home and pledges her coöperation in the great work of maintaining and increasing the dignity and usefulness of that profession in which the genius of the American people is perhaps most typically exemplified.

NICHOLAS MURRAY BUTLER, *President*

SMITHSONIAN INSTITUTE

WASHINGTON, U. S. A., *March 20, 1907*

TO THE ENGINEERING SOCIETIES

I regret that owing to the meeting of the National Academy of Sciences occurring on April 16 and 17, in Washington, I shall be unable to be present at the dedication of your new building.

But I rejoice that we have an American citizen who is interested in American Engineering and its societies to such an extent as to give them a home. It is an illustration of what good accumulated wealth can do when wisely administered.

Sincerely yours,

CHARLES WOLCOT

ILLUMINATED GREETING

PHILADELPHIA, PA., *April, 1907*

The Provost, Trustees and Faculty of the University of Pennsylvania extend felicitations and greetings to the President and Board of Trustees of the United

Engineering Societies upon the occasion of the dedication of the new building given by Mr. Andrew Carnegie as a home for American Engineering Societies, and they further express the cordial congratulations of the University of Pennsylvania for this notable instrument to consolidate and upbuild the profession of engineering in the United States of America.

THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA
CHARLES C. HARRISON, *Provost*
CLAYTON P. MCMICHAEL, *Acting Secretary*

THE STATE UNIVERSITY OF NORTH DAKOTA

UNIVERSITY, N. D., *April 6, 1907*

TO THE ENGINEERING SOCIETIES

On behalf of the University of North Dakota I beg to acknowledge the receipt of your very courteous invitation to this institution to be represented through an authorized delegate on the occasion of the dedication of the building given by Mr. Carnegie as a home for American Engineering Societies, on the 16th and 17th of this month. I greatly regret that other engagements render it impossible for me to be present on that occasion and that it seems impracticable for the University to send a representative.

Of all Mr. Carnegie's splendid philanthropies, it is difficult to say which is the most admirable, but certainly few do him greater honor than does the splendid gift which is to be fittingly celebrated by the American Societies of Engineering.

The University of North Dakota sends most hearty greetings and extends its congratulations to the American Engineering Societies upon the acquisition of so beautiful a home.

I have the honor to be,

Very respectfully yours,
WEBSTER MERRIFIELD, *President*

STEVENS INSTITUTE OF TECHNOLOGY

HOBOKEN, N. J., *April 10, 1907*

TO THE ENGINEERING SOCIETIES

I am in receipt of your invitation to say a few words of felicitation and congratulation as the representative of the technical institutions of learning on the occasion of the dedication exercises of the building of the Engineering Societies.

It is with extreme regret that I have to announce my inability to be present on this important occasion.

On behalf of The Stevens Institute of Technology and on behalf of the other schools of technology, if they will permit me to speak for them, I congratulate the three Engineering Societies who are to find a permanent and common home through the far sighted liberality of Andrew Carnegie.

I do not believe that any of us are capable of estimating the permanent good that may follow from the opportunities that will come through a community of interests thus established. The engineers of America have frequently evidenced their willingness and capacity for unselfish coöperation. The event that you are celebrating today will unquestionably act to stimulate this policy.

Further, I hope and believe that the establishment of this engineering center will definitely tend towards more active coöperation between those active in the administration of the schools of technology and those active in the fields of engineering.

Sincerely yours,
ALEX. C. HUMPHREYS, *President*

MESSAGE FROM THE UNIVERSITY OF MICHIGAN THROUGH MR. ALFRED NOBLE

The Senate of the University of Michigan has conferred on me the honor of representing it here today. The University, which came into being seventy years ago through an act of the legislature passed only two months after the admission of the State into the Union, was one of the first in the West to be organized on a broad plan, following, as its resources permitted, the German idea of a university. A provision for engineering education soon followed and its Engineering school took place in the first rank more than half a century ago and has now developed into a department of the University with a thousand students.

The University therefore takes the keenest interest in the advancement of the profession of Engineering which it has done so much to foster, and heartily congratulates the United Engineering Societies on the acquisition of this magnificent building as a Capitol of Engineering in America and which, it is confidently believed, will serve a beneficent purpose in strengthening and uniting the several branches of the profession so that it may better aid in promoting the growth of civilization and the welfare of mankind.

The University joins in the tribute to the iron master whose genius for organization and coöperation was the greatest single force in building up the iron industries of the United States; to the broad minded citizen whose wise benevolence has contributed so much to the benefit of the people of this and of other countries, and to whose unparalleled liberality the profession of Engineering today gratefully acknowledges its deep obligation.

ILLUMINATED GREETING

The Society of Beaux Arts Architects takes great pleasure in presenting its felicitations to the United Engineering Society on this occasion which marks the union binding the diversified aims and utilities of its members into one harmonious body, with one home, one government, and infinite scope in the far reaching field of its activities.

The bond between your Society and the one which I represent, is most clearly emphasized by the fact that the great structure of which you yesterday took possession, the magnificent gift of Mr. Andrew Carnegie, was designed by two of our most distinguished members, as architects, working in collaboration with distinguished members of yours.

And this bond will ever grow closer as the world recognizes the affiliation between the Engineer and the Architect; and, in speaking for the Society of Beaux Arts Architects, I may say that we all look forward in confidence to the relations between these two Societies that they will continue in that same spirit of coöperation and of harmony which has always marked them.

I beg to remain, sir,

Yours very respectfully,
LLOYD WARREN, *President*

OBITUARY

EUGENE GRIFFIN

Eugene Griffin was born in Ellsworth, Me., October 13, 1855, and was educated in the public schools of that place until he entered the United States Military Academy at West Point, from which institution he was graduated in 1875, standing third in his class.

Immediately following his graduation, he was appointed Second Lieutenant of Engineers in the United States Army, and was assigned to duty at the Engineering School of Application at Willet's Point, where he remained until 1877. During the years 1878–1880 he was in charge of a party of engineers in the United States Geographical Survey in Colorado, New Mexico, Arizona, and Texas. He was promoted to First Lieutenant in 1880 and was in charge of surveys of Governor's, Ellis and Bedloe's Islands in New York harbor.

From 1883 to 1885, he was Assistant Professor of Civil and Military Engineering and the Art of War at West Point. In 1885 and 1886 he was aide-de-camp to Gen. Winfield Scott Hancock. From 1886 to 1888 he was Assistant Engineer Commissioner of the District of Columbia, having charge of all matters pertaining to electric lighting, telegraph and telephone companies in the city of Washington. In 1887 he was promoted to Captain in the Corps of Engineers, and early in the year 1888 entered the employ of the Thomson-Houston Company to organize and manage its Railway Department, then just being formed.

In 1892 the General Electric Company was organized and absorbed the Thomson-Houston and Edison General Electric Companies. Captain Griffin was elected Director and First Vice President of the new company, which official positions he held at the time of his death.

Upon the declaration of war with Spain in 1898 he was commissioned by President McKinley to organize the First Regiment of Volunteer Engineers. He was promoted to the rank of Brigadier General prior to his regiment being mustered out of service, and at the close of the war he resumed his active duties with the General Electric Company.

He was a member of the Union University, and the Army and Navy Clubs, and one of the Board of Trustees of the Engineers' Club. He was a member of The American Society of Civil Engineers, The Ameri-

can Institute of Electrical Engineers, and became a member of this Society in 1889.

General Griffin was buried at West Point with military honors on Saturday, April 13.

WILLIAM H. DERBYSHIRE

William H. Derbyshire was born in Canton, Ill., in March, 1859, and graduated from The Polytechnic College of Pennsylvania in June, 1877. In August of the same year he accepted a position with John Roach & Son, Shipbuilding and Engine Works, Chester, Pa. In 1879 he became associated with The Miles Machine Tool Works, remaining with them until their consolidation with Wm. B. Bement & Son, forming the firm of Bement, Miles & Co. With the new company, he was made general superintendent, and remained with them in this capacity until November, 1897, when he formed the Chambersburg Engineering Company, Chambersburg, Pa., of which he was president until his death.

Mr. Derbyshire made a specialty of smith shop and boiler equipment and secured several patents on hydraulic equipment, one of the best known of which is the system of quick acting hydraulic riveters and presses. He became a member of the Society in 1890, and died April 13, 1907.

EMPLOYMENT BULLETIN

The Society has always considered it a special obligation and pleasant duty to be the medium of securing better positions for its members. The Secretary gives this his personal attention and is most anxious to receive requests both as to positions and as to men available. Notices are not repeated except upon special request. Copy for notices in this Bulletin should be received before the 15th of the month. The list of men available is made up entirely of members of the Society and these are on file, with the names of other good men, not members of the Society, capable of filling responsible positions, information about whom will be sent upon application.

POSITIONS AVAILABLE

049 Superior draftsman on design and some outside work. Location, New York.

050 Draftsman gas producer work; design and erection. Location, New York.

051 Superintendent of ornamental metal foundry, having had experience in general electric work, chemistry of iron, competent to cast all grades of brass and iron work, such as electroliers, registers, etc., and to make estimates. Permanent position and advancement promised. Salary to start, $2000. Location, New York State.

MEN AVAILABLE

In addition to the list of men available, the Society is pleased to announce that one of the colleges has volunteered to undertake to supply both undergraduate and graduate students for part time, summer and permanent positions. The Secretary will be pleased to be the medium for correspondence.

85 Member who has successfully filled positions of machinist, foreman tool department, having charge of over 1000 machines; draftsman, designer of special machinery and superintendent; superintendent of one concern ten years; at present holds position of superintendent, desires responsible position. Salary, $3000.

86 Draftsman or salesman open for engagement.

87 Position desired in central station management and heavy electric traction. Salary, $1500 to $1800.

88 Engineer in chief; long experience in charge of mechanical equipment, erection and maintenance of buildings at various plants. Factory manager.

89 Junior member, thirty-one years of age, desires a change in position. Seven years' drawing-room experience, designing Corliss engine boilers, mining machinery, power plants and special work. Three years machine shop, three years special work on road inspecting, erecting, and selling. Desires position as salesman with some manufacturing concern in the Middle States.

ACCESSIONS TO THE LIBRARY

BOOKS IN THIS LIST HAVE BEEN DONATED BY PUBLISHERS.

HENLEY'S TWENTIETH CENTURY BOOK OF RECIPES, FORMULAS, AND PROCESSES. Containing Nearly Ten Thousand Selected Scientific, Chemical, Technical, and Household Recipes, Formulas, and Processes for use in the Laboratory, the Office, the Workshop and in the Home. Edited by Gardner D. Hiscox. *The Norman W. Henley Publishing Company. New York, 1907.* Cloth, 8vo. Price, $3.

MODERN AMERICAN LATHE PRACTICE. By Oscar E. Perrigo. *The Norman W. Henley Publishing Company. New York, 1907.* Cloth, 8vo, 416 pp., 314 engravings. Price, $2.50.

Contents, by chapter headings: History of the Lathe up to the Introduction of Screw Threads; The Development of the Lathe Since the Introduction of Screw Threads; Classification of Lathes; Lathe Design; The Bed and its Supports; Lathe Design: The Head Stock Castings, the Spindle and the Spindle Cone; Lathe Design: The Spindle Bearings, the Back Gear and the Triple Gear Mechanism; Lathe Design: The Tail-Stock, the Carriage, the Apron, etc. Lathe Design; Turning Rests: Supporting Rests; Shaft Straighteners, etc. Lathe Attachments; Rapid Change Gear Mechanisms; Lathe Tools; High-Speed Steel; Speeds and Feeds; Power for Cutting-Tools, etc. Testing a Lathe: Lathe Work Continued; Engine Lathes; Engine Lathes Continued; Heavy Lathes; High Speed Lathes; Special Lathes; Regular Turret Lathes; Special Turret Lathes; Electrically Driven Lathes.

EXCHANGES AND PURCHASES

MODERN MACHINE SHOP CONSTRUCTION, EQUIPMENT, AND MANAGEMENT. By Oscar E. Perrigo. *New York, 1906.*

MODERN STEAM ENGINEERING IN THEORY AND PRACTICE. By Gardner D. Hiscox. Including chapters on Electrical Engineering by Newton Harrison. *New York, 1907.*

PUNCHES, DIES, AND TOOLS FOR MANUFACTURING IN PRESSES. By Joseph V. Woodworth. *New York, 1907.*

PROCEEDINGS OF THE ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA. Vol. 23, No. 2–3. *March* and *April, 1907.*

PROCEEDINGS OF THE UNITED STATES NAVAL INSTITUTE. Vol. 33, No. 1. *March, 1907.*

UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION. Bulletins 10–12. 1907.

REPORT ON THE COAL TESTING PLANT OF THE UNITED STATES GEOLOGICAL SURVEY AT LOUISIANA PURCHASE EXPOSITION, ST. LOUIS, MO., 1904. PART I, FIELD WORK, CLASSIFICATION OF COALS; CHEMICAL WORK. PART 2, BOILER TESTS. PART 3, PRODUCER GAS; COKING; BRIQUETTING; WASHING TESTS.

REPORT OF THE BUREAU OF LABOR STATISTICS OF THE STATE OF CONNECTICUT. *1906.*

CANDIDATES FOR MEMBERSHIP

Record of Qualifications, Engineering Experience and References

This list should be treated as confidential and is subject to inspection by members of the Society only. The names are those of candidates whose applications have been approved by the Membership Committee and the Council. The names appear in the same order as on the ballot sent to the voting membership, closing March 30, 1907.

TO BE VOTED FOR AS MEMBERS

ROBERT ANDERSON, Ivorydale, O. Born:—Cincinnati, Ohio, April, 1861. Drafting room. The Proctor & Gamble Co., Ivorydale, O., 1891-93. Shop experience: The Proctor & Gamble Co., Ivorydale, O., 1893-1900. Other engineering work: Assistant engineer Proctor & Gamble Co., 1900-1902. Chief engineer from 1902 to present time, charge of the equipment of oil refinery at Ivorydale; also new plant at Kansas City. Laid out and prepared plans and details for equipment of new plant at New York. Present position: Chief engineer, The Ivorydale plant, Proctor & Gamble Co.

References: Walter Laidlaw, E. T. Hannam, James B. Stanwood, Geo. W. Galbraith, W. B. Mayo, Chas. W. Aiken.

EARLE JACKSON BANTA, Culebra, Canal Zone. Born Benton, Elkhart County, Ind., Dec., 1875. Education: M.E. Purdue University. Apprentice Chas. F. Elmes Engineering Co., 1895. Drafting room: H. M. McCormick Co., Chicago, 1899-1900. Hastings Wool Boot Co., general reconstruction, 1901-1902, Crane Co., Chicago, 1902-1903. Shop experience: Machinist Fred W. Wolf & Co, Chicago. Chicago Automobile Co., Chicago, Fairbanks Morse & Co., Chicago, foreman of coaling station. Other engineering work: 1903-1904. Isthmian Canal Commission. Acting Master Mechanic in the Bas Matachin Shops. Built up the Organization taking charge of the shops and putting them into operating condition with the Mechanical Engineer. The shops included, machine shop, car repair shop, foundry, blacksmith shop and boiler shop. Transferred to the general office and given charge of the technical work with the title of Master Mechanic. Appointed Mechanical Engineer, April 1, 1906. Designed the various buildings for the Cristoba shops, Bas Matachin shops and for the new Empire and Paraiso Shops which are under construction. Present position: General supervision over the mechanical division which includes machine shops, all rolling equipment and steam shovels. At present a member of the Board of Survey and

Appraisal of the Commission which consists of surveying and appraising the various properties of the Commission.

References: W. F. M. Goss. Michael Joseph Golden, J. D. Hoffman, Harry Sawyer, E. C. Cummings, C. A. Strom.

PAUL PERCY BIRD, 5859 Washington Ave., Chicago, Ill. Born: Kalamazoo, Michigan, 1877. Education: Cornell University, M. E., 1900. Apprentice: Iron Foundry trade with Union Foundry Co., Rochester, N. Y., from 1893-1894. Drafting room: Newport News Shipbuilding Co., Newport News, Va., 1900-1904, and from 1904-1905. Other engineering work: Instructor in marine engineering at Cornell University, 1903-1904. Since May, 1905, with Illinois Steel Co., Chicago, Ill., South Works. Present position: Steam Engineer with above Company.

References: W. W. Bird, R. C. Carpenter, W. F. Durand, H. Freyn, C. E. Sargent.

ALLAN SMITH BIXBY, Indianapolis, Ind. Born: Philadelphia, Pa., September, 1870. Education: B. S., Rose Polytechnic Inst., 1892. Drafting room: Designing, Ewart Mfg. Co., 3 years. Shop experience: Ewart Mfg. Co., Indianapolis, Ind., 4 years. Other engineering work: Supt. of The Metallic Mfg. Co., 1 year. Engineer, Central Cycle Co., 1 year. Supt. The National Malleable Castings Co., 5 years. Present position: Supt. National Malleable Castings Co.

References: James M. Dodge, Stanton Peck, Charles Piez, Thomas Gray, R. C. Stevens.

EDWIN MORTIMER BLAKE, Tucson, Arizona. Born: New York, June, 1868. Education: E. M., Columbia, 1890; Ph.D., Columbia University, 1893. Other engineering work: Assistant in mechanical engineering at Columbia University, 1890-1891. Assisted in remodeling testing machine. Conducted course in cement testing, and in engine indicating. Assistant in Mathematics, Columbia University, 1893-1895. Instructor in Mathematics, Purdue University, 1896-1898. Instructor in Mathematics, Univ. California, 1900-1904. Author of three investigations in kinematics published in American Journal of Mathematics and Trans. of American Mathematical Society. Present position: 1904 to date, Professor of Mechanical Engineering, University of Arizona. Organized course of instruction mechanical engineering. Planned and installed engine, pump and pipe line for protection of University from fire. Remodeled electric wiring of University. Have in progress installation of apparatus for new mechanical laboratory.

References: F. R. Hutton, C. W. Hunt, John J. Flather, Ira H. Woolson, W. F. M. Goss, M. J. Golden.

GEORGE A. BOYDEN, Baltimore, Md. Born: Altoona, Pa., July, 1854. Education: St. Francis College, Lovetta, Pa. Apprentice: P. R. R. in various shops. Drafting room: Developing inventions and architecture under E. G. Lynd, Baltimore, Md. Shop experience: Penna. shops, Altoona, Pa. Boyden Air Brake Co., Baltimore, Md. Other engineering work: Inventor and patentee, Boyden Air Brake. Patent Attorney. Full engineering charge, Boyden Air

Brake Co. National Compositype Co., Baltimore. Present position: Mechanical Expert and Cons. Engr., Westinghouse Air Brake Co.

References: J. S. Detrick, F. H. Easby, Henry Adam, Pierre O. Keilholtz, E. W. Grieves.

WILLIAM CHARLES BOYD, Pittsburg, Pa. Born: Allegheny, Pa., 1871. Education: Rensselaer Polytechnic Institute, 1895. Drafting room: Carnegie Steel Co., Duquesne, Pa., four months, 1895. Blast furnace design American Steel Hoop Co., Etna, Pa., six months, 1901-1902. Other engineering work: Engaged as locating engineer for six years, 1895-1901, at Duquesne, Pa., for the Carnegie Steel Co., engaged on the construction of blast furnace, open hearth furnaces, rolling mills, and accessories. For three years' time had charge of all location of buildings, foundations, sewers, tracks, etc. Nine months in 1901, construction engineer, Dominion Iron and Steel Co., Sydney, N. S., in full charge of construction of plant. Present position: Assistant Engineer, Pittsburg Railway Co., Pittsburg, Pa.

References: Daniel Ashworth, J. M. Graves, J. J. Hoppes, D. S. Kohler, Geo. J. Foran, W. B. Yereance.

CARL D. BRADLEY, Elizabeth, N. J. Born: Chicago, Ill., 1860. Education: Six years Allen's Academy, Chicago, Ill. Drafting room: In charge of design of many gas works plants, refrigerating and ice making plants, dredge boat machinery and equipment, architectural iron works, and special machinery and apparatus. Shop experience: President of International Smokeless Powder & Chemical Co., 4 years. One and one-half years engaged in contracting work. Foundry and machine shop work, covering a period in all of 20 years. Present position: President of Samuel L. Moore & Sons, Corp., engaged in active management of the company.

References: George J. Roberts, Samuel H. Libby, David B. Carse, John B. Carse, John Lathrop Gray.

HENRY BREWER, New Haven, Conn. Born: New Haven, Conn., May, 1872. Education: Ph.B., Yale, 1904. Apprentice: Winchester Repeating Arms Co., Machinist Trade, 1905-1906. Drafting room: Two months, Sargent & Co., New Haven, 1904. Shop experience: Year and half as machinist's apprentice. One year general experimental work on guns and ammunition. Other engineering work: Administration and experimental work of various kinds in cartridge department of Winchester Repeating Arms Co. Present position: Manager Cartridge Department, Winchester Repeating Arms Co.

References: Chas. B. Richards, A. Jay Dubois, Frank L. Bigelow, Henry B. Sargent, Wm. Mason, Arthur Brewer.

WILLIAM C. BRIGGS, Elizabeth, New Jersey. Born: Poland, Maine, July, 1870. Education: Four years Hebron Academy, Hebron, Maine. Apprentice: Chas. L. Seabury Works, Nyack, N. Y., 1892-1895. Marine Engines and boilers for high speed steam yachts, torpedo boats and merchant vessels. Shop experience: Assistant foreman machine shop, Chas. L. Seabury & Co., Gas Engine Power Co., 1897-1901. Other Engineering work: Foreman of machine shop, building marine engines and other work contracted for by Samuel L. Moore &

Sons Company, 1901-1904. Present position: Works Superintendent for Samuel L. Moore & Sons.

References: D. G. Moore, Harris Tabor, Gardner C. Sims, Malcolm N. MacLarne, J. Alvah Scott, John L. Gray.

HENRY K. BROOKS, 22 Thomas St., New York City. Born: Kettering England, 1869. Education: Three years private instruction; 3 years Leicester Technical Evening College; received two government certificates for drawing. Apprentice: Gimson & Co., Leicester, Eng. Other engineering work: Midland Railway Co., Eng., on locomotive work, 1887; 1888, A. T. & S. F. R. R. Co., Southern Kansas and Southern Pacific Railways Cos., three years; charge of department. 1895 Kansas State Agricultural College Instructor. Charge of the foundry, blacksmith and machine departments; 1896, general manager Capitol Iron Works of Topeka, Kansas, complete charge. Carried out many important government railroad and state contracts for structural iron and machinery. Mechanical Engineer Electric Axle Light & Power Co., New York, charge of equipment in operation on railroad, 1899. Asst. chief engineer Consolidated Railway, Light & Equipment Co., 1900. Charge of factories, New York and Conn., improvements in electric train lighting apparatus. Present position: Chief Engineer United States Light & Heating Co., for past five years.

References: William McIntosh, G. R. Henderson, C. W. Rice, F. M. White, D. B. Bullard.

CHARLES ELI BURGOON, 360 Pearl St., Brooklyn, N. Y. Born: Estelle, Tex., November, 1872. Education: B. M. E., Texas Agricultural and Mechanical College, 1895; M. E., Texas Agricultural and Mechanical College, 1899; M. E., Cornell University, 1905, M. M. E., 1906 Drafting room: Fore River Shipbuilding Co., Quincy, Mass., 1906-1907, computed curves for Entropy-temperature, and Heat-Entropy Diagrams. Detail drawings Curtis Marine Turbine and general drawings. Other engineering work: Assistant engineer Texas Agricultural and Mechanical College, Sept.-July, 1896. Asst. professor of Mechanical Engineering, 1896-1901. Engineer Southern Pacific Railroad Co., Houston, Tex., 1901-1902. Designed, supervised the construction, and operated a large wood preserving plant, general signal foreman, 1902-1904. Designed, supervised the construction, maintained and operated a number of interlocking plants. Draftsman, Edison Illuminating & Power Co.

References: R. H. Whitlock, A. W. Smith, R. C. Carpenter, W. N. Barnard, H. W. Hibbard, D. S. Kimball.

JOHN A. CALDWELL, 45 Broadway, New York, N. Y. Born: Scotland, August, 1849. Education: Three years Glasgow School of Design and Mechanical Engineering. Apprentice: Five years tool shop Tweedale and Robinson & Lawson & Son; Johnstone & Glasgow as Patternmaker and Draftsman, 1863-1868. Draftsman, Mackintosh, Hemphill & Co., Pittsburg, Pa., 1870-1874. Designing large rolling mill engines, Bessemer Steel Works; entire charge of erection work and rebuilding; erection of two new blast furnaces at Port Washington, Ohio. Entire charge of designing locomotives, Nat. Locomotive Works, Connellsville, Pa., 1875-1876. Shop experience: Mackintosh Hemphill, 1876-1877. Contracting Engineering, W. H. H. Bowers & Co., mining work, including complete designing and erecting Alice Stamp mill, Butte, Mont., Moulton mill, and eleva-

tor service, Z. C. M. I., Salt Lake, 1877-1879. Conducted Engineering office with Morey & Sperry, designing and erecting stamp mill at Parrall, Mexico, 1880-1882. Mechanical Engineers, H. W. Johns Co., Brooklyn, charge of additions, buildings and new machinery, 1883-1886. Contracting, designing, Supt. filter plants for Hyatt Pure Water Co., including city plant, Oakland, Cal., 1887-1892. Contracting and Supt. erecting Blower plants, water pumps and pumping stations, P. H. & F. M. Roots Co., 1892-1895. Contracting, designing and Supt. erecting water tube boiler plants, 1895-1899. Business Manager American Stoker Co., N. Y., 1899-1901. Present position: In own business, General Engineering, 1901 to date.

References: Wm. J. Baldwin, Paul H. Grimm, H. G. Stott, Reginald P. Bolton, Geo. H. Barrus.

JAMES M. CARPENTER, Pawtucket, R. I. Born: Cumberland, R. I., March, 1838. Apprentice: Arnold's Machine Shop, Pawtucket, R. I., cotton machinery, 1853-1856. Shop experience: Journeyman machinist Corliss Engine Co., Providence, R. I. Browne & Sharpe Mfg. Co., Providence, R. I., Florence Sewing Machine Co., 1856-1870. Other engineering work: Burnside Rifle Co., on gun tools. Organized J. M. Carpenter Tap & Die Co., 1870, invented, designed and built special machines for making taps and dies, still in successful use. Present position: President, treasurer and general manager, J. M. Carpenter Tap & Die Co.

References: Wilfred Lewis, Henry D. Sharpe, Geo. M. Bond, Chas. C. Tyler, Horace K. Jones, Frank P. Sheldon.

GEORGE EDWIN CHAMBERLAIN, Chicago, Ill. Born: Wyalusing, Pa., 1870. Education: A. C. Lehigh University, 1903. Drafting room: Designed water works, Wyalusing, Pa., 1893. Other engineering work: Rebuilt glucose factory at Marshalltown, Ia., 1900, Rockford, Ill., 1901. Remodeled and increased certain parts of starch factories at Indianapolis, Cincinnati, Buffalo and Oswego, 1902. Designed and built glucose factory at Granite City, Ill., 1903. Present position: Manager of Construction Corn Produce Manufacturing Co.

References: A. Bement, Fred'k L. Jefferies, Jas. W. Lyons, Wm. S. Love, Edward C. Wells.

ANDREW CHRISTIANSON, Std. Steel Car Co., Butler, Pa. Born: Gran Hadeland, Norway, April, 1868. Education: Technical College, Horton, Norway. Continued studies for two years at Technical High School, Dresden, Germany. Apprentice: Locomotive Machine Shops of C. & N. W. Ry., Winona, Minn., 1895-1898., in shops and office. Drafting room, C. R. R. of N. J. as locomotive and car draughtsman, 1898-1900. Chief draughtsman in general drawing room of Standard Steel Car Co., 1902-1903, with force of about 25 men. Other engineering work: Engineer of construction, 1903-1904, assuming the responsibility of the quality of workmanship of cars and car parts entering into finished products or plant's output from over 3,000 employees. Chief Engineer, 1904-1906, having direct charge of the entire engineering corps, numbering over 50 men embracing the ordering and estimating of engineering proper, and including the work of designing of all classes of car construction, dies and tools as well, for forming the various pressed steel parts. In charge of engineering of subsidiary plants.

particularly hydraulic machine equipment for new forged steel wheel plant at New Castle, Pa. Designed first steel mail car built, exhibited at International Railway Congress, Washington, D. C., 1906.

References: John W. Seaver, Wm. McIntosh, G. W. Wildin, C. Von Phelps, F. F. Gaines, Geo. W. Basford.

GEORGE B. CONRATH, 443 East 6th Street, Erie, Pa. Born: Erie, Pa., June, 1868. Education: Technical, 3 years, Erie. Apprentice: Nagle Engine & Boiler Works, Erie, Pa., Patternmaker, 1884-1888. Drafting room: Nagle Engine & Boiler Works; foreman pattern shop, 1887-1890; Drawing room, 1890-1893; Drawing room, charge, 1893-1898; Superintendent Works, 1898 to date Other engineering work: Charge design and construction of boiler shops including buildings, machinery installation and design of special machinery for same. Charge of design and construction of machine shops. Design, manufacture and sale of stationary and portable boilers, throttle valve, automatic, and Corliss engines. Present position: Superintendent, Nagle Engine & Boiler Works.

References: Walter J. Brock, Franklin M. Bowman, Ernest R. Behrend, Rudolph Conrader, Alex. Jarecki.

AUSTIN R. DODGE, General Electric Company, Schenectady, New York. Born: Southbridge, Mass., 1869. Education: B. S., Worcester, 1893, and M. E., 1905. Apprentice: General Electric Co., Schenectady, N. Y., 1896, general testing, electrical and apparatus. Other engineering work: Charge of all turbine work, Schenectady, 1896-1899. Charge of Experimental Turbine Dept. since 1899. Developed new type of steam flow meter now manufactured by Gen. Elec. Co. Designed and operated several sixty absorption dynamometersup to 1,000 H. P. capacity. Present position: Engineer, Experimental Steam Turbine Dept.

References: Geo. J. Foran, R. H. Rice, W. B. Potter, John Riddell, Geo. H. Barrus, F. A. Larkin.

WILLIAM A. FANNON, Appleton, Wisconsin. Born: Philadelpiha, Pa., April, 1863. Apprentice: Southwark Foundry and Machine Co., Philadelphia, Pa., Machinist, 1880-1884. Drafting room: Bullock Printing Press Company. Shop experience: Chas. Lafferty, Gloscestor, New Jersey, 1884. Gloscestor Iron Works, New Jersey, running machine tools, 1885. John Dialogue, New Jersey, ship building and engines, 1885. Philadelphia & Fall River Line Steamers, in engine room and repairs, 1886. Wm. Cramp & Sons Ship Building Co., Philadelphia, Pa., installing engines in vessels, 1886. Wm. Wharton & Co., Philadelphia, running machine tools, 1887. Other engineering work: Midvale Steel Company, Philadelphia, foreman in Engineering Dept., 1887 and 1888. Middletown Machine Company, Middletown, Ohio, foreman and partner, assist design specialties, 1888 and 1889. Scott Machine Company, Denver, Col., 1889 and 1890. Midvale Steel Co., foreman and assistant to chief engineer, 1890 and 1891. Assistant superintendent, superintendent and manager, 1891-1907, Interlake Pulp and Paper Company. Present position: Also President of Valley Iron Works, Appleton, Wisconsin.

References: Frederick W. Taylor, A. A. Stevenson, George M. Brill, George W. Nistle, Stephen G. Hobart., Geo. M. Sinclair.

RICHARD FAULL, Birmingham, Ala. Born: London, England, December, 1868. Apprentice: Simpson & Co., London, Machinist, 1882-1889. Drafting room: Soudan, Minnesota, Minnesota Iron Co., 1899-1901. Shop experience: Soudan, Minnesota, Minnesota Iron Co., 1889-1899. Other engineering work: Shop foreman and master mechanic with Minnesota Iron Co. General master mechanic with Tennessee Coal, Iron and Railroad Co. Designing erections of mining machinery with Tennessee Coal, Iron and Railroad Co., 1901-1906. Present position: Mechanical Engineer, mining division of Tennessee Coal, Iron and Railroad Co.

References: John W. S. Jones, Wm. Hardie, B. V. Nordberg, F. M. Prescott, H. Unzicker.

BRUCE FORD, Philadelphia, Pa. Born: Brooklyn, N. Y., 1873 Education: Brooklyn Polytechnic Institute 2 years; Franklin Institute 1 year (night school). Apprentice: The United Elec. Improvement Co., Gloucester, N. J. Heisler Electric Co., 1890-1891. Drafting room: Heisler Elec. Co., Gloucester, N. Y., 1891-1892. Johnson Co., Johnstown, Pa., 1892-1894. Shop experience; The Johnson Co., Lorain Steel Co., The Steel Motor Co., Johnstown, Pa., 1894-1898. Other engineering work: Holds a number of patents for mechanical and electrical apparatus, many of which are in commercial operation. Special draftsman to master mechanic of the Johnson Co., 1893. Piece-work rate fixer of same, 1897, and engaged in the development and installation of a contact railway system for Johnson Co. at Washington, D. C., 1897. The Electric Storage Battery Co., assistant to chief engineer of Railway Dept., 1898. Engineer in charge of department of development and design The Electric Storage Battery Co., 1900 to date.

References: F. W. Taylor, Geo. J. Roberts, Ward Raymond, Fred A. Phelps, Robt. B. Owens.

FLOYD WILLIS FREDERICK, Stroudsburg, Pa. Born: Catasauqua, Pa., Feb., 1876. Education: E. E. Lafayette College, 1896. M. M., 1901. Apprentice: Erecting shops of L. V. R. R., summers of 1892-1895. Drafting room: Chief Draftsman, and entire charge of design with S. Flory Mfg. Co., Bangor, Pa., half of 1896, 1897 and 1898. Six months designer with Russell Engine Co., at Massellon, O.; 6 months estimator P. R. P. R., St. Paul, Minn. Shop experience: One and one-half years designing draftsman and assistant engineer of tests with L. V. R. R. at Easton, Pa. Locomotive work and testing of all kinds of materials used in mechanical construction. Other engineering work: 1902-1903 in charge of mechanical design of large unit A. C. generators with Westinghouse Electric & Mfg. Co. Appointed Foundry Representative for Westinghouse Machine Co. for 3 years. Present position: Superintendent and mechanical engineer The Stroudsburg Engine Works.

References: Wm. N. Barnard, David W. Pell, Edward S. McClelland, C. W. Rice, Frederick F. Gaines.

ERNEST ALBERT GARRATT, London, England. Born: Clapton, London, June, 1874. Education: St. Johns School, London. Apprentice: London, Brighton and South Coast Railway locomotive works, 1891-1894. Drafting room: Jacobs & Barringer and Alexander Leask. Shop experience: Marine engine work, 1894-1899, held successively positions of 4th, 3d, 2d, and chief engineer.

First class board of trade certificate for foreign service. Other engineering work: Assistant engineer Electric Lighting Station, Manchester, London, engineer representative Goulro & Scrutton, London, Messrs. Jacobs & Barringer, consulting engineer, assistant engineer. Personal supervision of repairs and assistant superintendent steamship lines, C. T. Bowering, London and Liverpool. Scrutton of London, England, Haslehunt & Burmah Oil Co., London and Rangoon. Designs, estimates, construction of various oil plants, etc., 1901-1904. Time occupied in designing oil storage installations for the British Admiralty, design and inspection of material, charge of construction, pipes, pumps, tanks, foundation, etc. Present position: Chief assistant to Messrs. Jacobs & Barringer, London, New York and Boston.

References: Lloyd I. Redwood, J. Blencowe, Walter Laidlaw, William Schwanhausser, Geo. J. Foran.

WILLIAM EMERY GRAY, Williamsport, Pa. Born: Lewisburg, Pa., February, 1863. Education: Two and one-half years Cornell University. A.B, Dickinson, 1881. Apprentice: Hendey Machine Co., Torrington, Conn., 1881-1883. Drafting room: One year D. E. Whiton Machine Co., New London, Conn.; 1 year Kensington Engine Works, Philadelphia. General draughting work on power plants for the last fifteen years. Shop experience: H. D. Bigelow, Co., New Haven, Conn. Gaynor & Fitzgerald, New Haven, Conn. Other engineering work: two years at Kensington Engine Works, Philadelphia, as draughtsman and erection man, also selling. Three years at Link Belt Eng. Co., Phila., Supt. erection power plants, assistant to superintendent, general foreman and experimental work, erection also building special machinery in plant for Holmes Fiber Graphite Bearings. Two years chief engineer, Harrison Bros. & Co., Phila., full charge mechanical work, designing new and improving old machinery. One year General Manager, Campbell & Zell Co. One year selling and testing Acme Mechanical stokers. Five years Asst. Mgr., N. Y. Office Hoover, Owens & Rentschler Co., selling, erecting, and designing complete power plants. Present position: Asst. General Manager E. Keeler Co., Williamsport, Pa.

References: Jay M. Whitham, R. G. Carpenter, H. L. Stevens, Harris J. Ryan, Henry W. Bulkley, Geo. F. Hardy, James M. Dodge.

W. HERMAN GREUL, New York. Born: New Jersey, October, 1875. Education: Three years Drexel Institute, Philadelphia; 1 year Tufts College. Drafting room: New England Gas & Coke Co., on erection of plant, 1898. Pennsylvania Iron Works Co., 1898-1901, and chief draftsman of gas engine department, and in charge of inspection and test of gas engines. With E. C. Warren, and others, as draftsman, 1901-1903. Chief draftsman with Dodge & Day, Philadelphia, in charge of improvements to machines of the Jeansville Iron Works Co., and Ingersoll, Sargent Co., Jan., to November, 1903. Other engineering work: Since 1903, designed marine gasoline engines for Vaughn Bros., Camden, N. J. Present position: From July, 1904, to date assistant superintendent of construction Otis Elevator Co., N. Y., in charge of installation of electric and hydraulic elevators, New York City, including the superivsion of installation of pumps, piping, etc.

References: Carl G. Barth, S. D. Collett, D. L. Holbrook, Geo. T. Gwilliam, A. T. Nickerson.

ROBERT ABBOTT HADFIELD, 28 Hertford St., London, England. Born: Sheffield, England, November, 1859. Education: Five years Sheffield College. Drafting room: Hecla Works, Sheffield. Other engineering work: Inventor of the Hadfield system comprising the special study and research work in alloys of iron with manganese, etc., many of which are largely used by mechanical engineers in England and America. Present position: Chairman and Managing Director for fourteen years of the Hadfield Co., Sheffield, England.

References: F. R. Hutton, John Fritz, C. W. Rice, S. T. Wellman, Chas. Wallace Hunt, Robt. W. Hunt.

RALPH BERGEN HAMILTON, St. Catharine, Ontario, Canada. Born: Toledo, Ohio, April, 1875. Education: Royal Inst. of Technology, Dresden, Saxony, 1 year. M. E., Cornell University, 1896. Drafting room: Buffalo engineering Co. (Buffalo), Engineering Contractors, 1896. Howard Iron Works, (Buffalo), chief draftsman and assistant superintendent, Elevator Department, 1897. Iroquois Iron Works, Buffalo, Machinery for Asphalt Paving, Chief Draftsman and Assistant Superintendent, 1898-1900. Shop experience: Howard Iron Works, Buffalo, 1897. Iroquois Iron Works, 1898-1900. Other engineering work: Packard Elec. Co., General Manager Chief Engineer for the past six years. Have re-equipped entire plant, including many machines, special tools designed by myself. Organized, devised new manufacturing departments. Devised organized complete cost system in all departments. Designed detail new shops, Automobile Department, making drawings. Supervised construction of buildings, planned tool equipment, organized entire department, which is now turning one complete Oldsmobile, 4 cylinder touring cars per day. In charge of three hundred employees; within the last two months created position Chief Engineer to relieve me of that portion of the work. Present position: General Manager, Secy-Treas., The Packard Elec. Co., Ltd.

References: C. H. Bierbaum, W. Grant King, Chas. M. Morse, Norman Harrington, Robt. B. Owens.

FREDERICK MORSE HEERMANN, 31 Milk Street, Boston. Born: Lawrence, Mass., December, 1867. Education: S. B. Mass. Inst. of Technology, 1896. Drafting room: Chapman Valve Mfg. Co., Indian Orchard, Mass., 1889-1890, laying out a line of high pressure steam valves. Factory Mutual Insurance Companies, mostly on the experimental work, 1890-1893. Factory, Mutual Co's as Surveyor and Draftsman, 1896-1899. Shop experience: Machine shop of Lower Pacific Mills, Lawrence, Mass., 1884. Machine shop of John McWilliams, Providence, R. I. Other engineering work: Inspector and Special Inspector Factory Mutual Co's since 1899, studying the fire hazards of, and designing protection for, manufacturing plants. Present position: Special Inspector and Engineer Factory Mutual Fire Insurance Companies.

References: Charles T. Main, Geo. E. Merryweather, John R. Freeman, Lewis H. Kunhardt, Edwin D. Pingree, Harry A. Burnham.

WILLIAM FERRIS HENDRY, 463 West Street, New York City. Born: Wellsboro, Pennsylvania, 1873. Education: Betts Academy, Conn., 3 years, Cornell University Special Engineering Work, 2 years. Apprentice: Baldwin Locomotive Works, Edison Elec. Co., Vacation 1888, 1889, 1890, Locomotives, Electric Motors. Shop experience: General Elec. Wks., student course, between

two years at College. Gen. construction work, 1895-1896. N. Y. Navy Yard, charge of power plant Cons. Dept., 1897-1899. Sprague Elec. Co., Erecting Engineer, 1899-1898. Western Elec. Co., Asst. Factory Engr., 1900-1902. Factory Engineer, 1902 to date. Entire charge and responsibility of Mechanical and Electrical Equipment of plant of 7000 employees. Designed and patented several motor controlling devices for machine tools, automatic return sand blast machine, automatic valves, and many details of general factory equipment. Present position: Factory Engineer.

References: H. F. Albright, H. M. Sage, F. A. Scheffler, O. S. Shantz, D. A. Wallace.

WILLIAM SMITH HUYETTE, Chicago, Ill. Born: Blair, Nebraska, November, 1870. Education: Three years private school, Ann Arbor, and special study. Apprentice: Detroit Blower Co., vacations 1886-1887-1888.; 6 months pattern shop, 2 months machine shop, 1 month foundry. Draughting room: Junior partner Thomas & Huyette, Detroit, 1889-1891; Detroit Electrical Works, Detroit, draftsman, chief draftsman, 1891-1893. Westinghouse El. & Mfg. Co., Pittsburg, 1893. Gilbert Wilkes, Cons. Engr., Detroit, charge of Steam Engineering Department, 1894-1898. Shop experience: Detroit Electrical Works, 1892-1893. Westinghouse El. & Mfg. Co., special tools, 1893. Other engineering work: In charge of heating and ventilating, Detroit Public Schools two years, designed and superintended construction of steam heating and ventilation of new schools and remodeled old systems. Designed and superintended construction heating and power plant Union Trust Bldg., Detroit; Wayne County Court House, Detroit, street railway power house in Saginaw. Present position: 1898 to date, Contracting Engineer, Chicago territory, Wickes Bros.

References: Mortimer E. Cooley, Wm. S. Love, S. Ashton Hand, Walter S. Russel, Geo. M. Brill.

JOHN PARRY JOHNSTON, Indianapolis, Ind. Born: Penn Township, Allegheny Co., Pa., 1869. Education: C. E. West University of Pa., 1890. Drafting room: Mt. Vernon Bridge Co., Bridge Draftsman, 1891. N. Z. Zinc Co., designing boiler house and special boiler setting, 1898-1899. Post & McCord (Brooklyn) charge, design and detail structural steel works. Shop experience: Engaged in summer vacations, Nine & Co. Surveying, McCully & Taylor, and Edeburn & Cooper (Pittsburg). Pa. Lines west of Pittsburg, Bridge Inspector, calculated strain sheets for forty bridges for Toledo Walhounding Valley & Ohio R. R. Co., 1890-1891. Resident Engineer Pittsburg Testing Labcratory, charge of bridge work, Memphis bridge approach and the St. Louis train shed. Babcock & Wilcox Co., Asst. Mechanical Engineer charge of tests of materials, shop, order dept. and purchases, 1892-1895. Babcock & Wilcox (Pittsburg) Salesman, 1895-1898. Passed Civil Service examination (New York) for Chief Inspector of boilers and engines on vessels Interna. Waters of N. Y. state and Examiner Engineers for License, 1899. Designing and Contracting Engineer, Berlin Iron Bridge Co., 1900. Alphous Custodis Chimney Co., western office, design, construction of radial brick chimneys, 1901-1905. Weber Steel Concrete Co., same position as with Custodis, 1905-1906. Present position: Sales Manager, Water Tube Boiler Co.

References: W. M. Sewall, Geo. H. Clapp, Thomas Elliott, Geo. M. Brill, W. S. Monroe.

HENRY OSGOOD LACOUNT, West Somerville, Mass. Born: Somerville, Mass., June, 1871. Education: S. B., Mass. Inst. of Tech., 1894 and 1895. Drafting room: Asso. Factory Mutual Fire Ins. Co., Plan Dept., June-July, 1895. Other engineering work: Inspection Dept. of Associated Mutual Fire Ins. Co., Boston, Mass., 1895 to date. Testing laboratories, electric and hydraulic, 1895-1900, assistant. 1900 to date charge of testing work, 1904 Engineer of Lab. Electrical inspection, 1895-1899. Inspector in charge this work during past few years; 1906 appointed engineer in charge of engineering work of Dept. including specification for apparatus and rules for installation. Present position: Engineer, electrical inspector, and engineer of laboratory of Insp. Dept. Asso. Factory Mutual Fire Insurance Co.

References: Walter E. Parker, Charles H. Fish, Walter M. McFarland, Peter Schwamb, Edward V. French.

SIMON LAKE, Bridgeport, Conn. Born: Pleasantville, N. J., September, 1866. Education: Clinton Liberal Inst., Fort Plain, N. Y. mechanical drawing at Franklin Inst., Philadelphia, shops of The Lake Mfg. Co., Ocean City, N. J., and J. C. Lake & Co., Baltimore, Md. Other engineering work: General experience in foundry and machine shops, designing and construction of various kinds of machinery and submarine vessels and appliances. Inventor "Lake" type of submarine boats. Member Soc. of Naval Architects and Marine Engs. Inst. of Naval Architects, American Soc. Naval Engrs. Present position: President, Lake Torpedo Boat Co., Lake Submarine Co., and Lake Heat Engine Co.

References: Frederic A. Parkhurst, Lebbeus B. Miller, Frank E. Holt, Hart O. Berg, Geo. W. Melville, Chas. H. Haswell.

HARRY CLAY LANE, Sparrows Point, Md. Born: Baltimore, Md., March, 1866. Education: Two years at B. & O. R. R. Co.'s Technological School, 3 years at Maryland School of Design. Apprentice: Mt. Clare, Baltimore, Md., B. & O. R. R. Co., Machinist trade, 1882-1886. Locomotive building and repairs, tools and stationary machinery. Drafting room: Draftsman and inspector for Supt. motive power B. & O. R. R. Co., 1893-1896. Draftsman and designer for Maryland Steel Co., 1898-1902. Shop experience: Machinist, B. & O. R. R. Co., 1886-1893. Machine shop foreman, Garrett, Ind., B. & O. R. R. Co., 1896-1898. Other engineering work: Maryland Steel Co., designing electric winches, electric motor cars, new electrically driven feed roller tables for 26" three high roll train. Re-designing 300 k.w. cross-compound vertical steam engine. Designing two 1000 tons capacity coal bunkers at coke ovens. 1902 to date, designing coke loaders and quenchers, installing coal handling and crushing machinery. Present position: Chief draftsman, Maryland Steel Co.

References: Simon S. Martin, Henry A. Magoon, Stephen W. Baldwin, Thos. H. Mirkil, Chas. Piez.

PAUL MARTYN LINCOLN, Westinghouse Elec. & Mfg. Co., Pittsburg, Pa. Born: Norwood, Mich., January, 1870. Education, M. E., Ohio State University, 1892. Drafting room: Brush Elec. Co., Cleveland, O., July-Nov., 1892. Other engineering work: Electrical testing and construction work, Westinghouse Elec. & Mfg. Co., 1892-1895. Electrical superintendent and resident electrician, Niagara Falls Power Co., 1895-1902. General Engineering work with Westing-

house Elec. & Mfg. Co., 1902-1904; engineer power division, 1094 to present time. Present position: Engineer power division West. Elec. & Mfg. Co.

References: A. Kingsbury, W. M. McFarland, Coleman Sellers, Edward A. Deeds, Calvin W. Rice.

O. D. McCLURE, Ishpeming, Mich. Born: Gibson City, Ill., April, 1868. Education: B. S., University of Illinois, 1891. Apprentice: Robinson & Burr. Drafting room: Link Belt Machinery Co., Chicago, Ill.; Sterling Gas Engine Co., Sterling, Ill.; Keystone Mfg. Co., Rock Falls, Ill..; Byron Jackson Machine Co., San Francisco, Cal. Shop experience: Robinson & Burr, Champaign, Ill.; Gibson City Iron Works, Gibson City, Ill.; Union Pacific R. R., Cheyenne, Wyo. Other engineering work: Level man, transit man, and engineer in charge of levee buildings, Mississippi River for U. S. Government. Assistant division engineer, Wyoming division of the Union Pacific R. R. Superintendent gas plant, Peoria Gas and Elect. Co., Peoria, Ill. Constructing engineer Akron Gas Co., Akron, Ohio. Master mechanic, San Fernando, Mexico Est. Durango. Salesman American Dist. Steam Co., Lockport, N. Y. Present position: Master Mechanic, Cleveland Cilffs Iron Co., Ishpeming, Mich., building and maintaining the mechanical, electrical and hydraulic equipment for a group of iron mines.

References: F. M. Prescott, R. S. Wallace, D. H. Maury, F. W. Richart, C. R. Bishop.

WILLIAM PERCIVAL MACKENZIE, Harrisburg, Pa. Born: New York, N. Y., April, 1871. Education: M. E., Stevens Inst. of Tech., 1893. Drafting room: Asst. Mgr. of Harrisburg Foundry and Machine works, Harrisburg, Pa., engaged in the design and manufacture of steam engines, 1898-1902. Other engineering work: In engineering department New York Steam Co., 1893-1896, finally as assistant engineer, planning and supervision of construction work, estimating, testing, etc. Chief engineer, Bayonne, N. H. Standard Oil Co. plant design and construction of new refinery built at that time; also of entire power plant equipment; 1902-1906, President of firm Mackenzie, Quarrier & Ferguson, Engineers and Contractors, New York, design and construction of power plants. Present position: Vice President and General Manager of the Harrisburg Foundry and Machine Works, Harrisburg, Pa., 1906 to date.

References: D. S. Jacobus, Forrest M. Towl, F. E. Idell, J. E. Denton, B. T. Allen.

JAMES H. MACLAUCHLAN, West New Brighton, N. Y. Born: Glasgow, Scotland, April, 1876. Drafting room: J. B. Sargent & Company, New Haven, Conn., 1892-1896. Other engineering work: Draftsman, Diamond Match Co., New Haven, Conn., 1896-1897. Singer Sewing Machine Co., Elizabeth, N. J., 1897-1898. Waterbury Machine Co., Waterbury, Conn., 1898-1899. E. W. Bliss Co., Brooklyn, 1899-1901. Atlas Portland Cement Co., Northampton, Pa., 1901-1902. Chief Draftsman, Edison Portland Cement Co., Stewartsville, N. J., 1903-1904. Mechanical engineer, Bath Portland Cement Co., Bath, Pa., 1904-1905. Chief Draftsman, C. W. Hunt Co., New York, 1905 to date.

References: C. W. Hunt, C. C. King, F. B. Franks, Emil Herter, James V. Colwell.

HARRY J. MARKS, New York City. Born: London, England, January, 1870. Education: Under private instructors. Apprentice: Machinist trade (Bookbinders' Machinery), W. F. Ellis, Centre St., N. Y., 1884-1887. Drafting room: Evening High Schools. Shop experience: Delamater Iron Works, 1887-1888. DeLaVergne Machine Co., 1888-1889. Engineering Dept., Iron Steamboat Co., 1889-1890. Operating and erecting steam plants and machinery, 1890-1898. Other engineering work: Designed complete steam wagon and supervised construction of same. Equipped the shops of the Empire State Engineering Co. Redesigned and reconstructed valve gear of Steamer "Fidelity" of the Department of Public Charities of New York. Present position: Manager of the Empire State Engineering Co.

References: J. J. Chisholm, F. R. Low, W. T. Wheeler, F. J. Wood, J. H. Dally.

JAMES AMBROSE MOYER, West Lynn, Mass. Born: Worcester, Pa., September, 1875. Education: S. B. in M. E. Harvard University, 1899. A. M., in Harvard University, 1904. Drafting room: W. S. Burke, Cambridge, Mass., heating and ventilation, June-Aug., 1899. L. J. Johnson, North Cambridge, Mass. Preliminary plans for Harvard Stadium, Aug. to Oct., 1899. Lieut. Commander, R. C. Smith, U. S. N., topographic and map drawing, 1899-1900. Other engineering work: Asst. in Lawrence Scientific School, electrical engineering and mechanical drawing, 1899-1900; with L. S. Marks, May to Oct., 1900, on power and refrigerating plants for Memorial Hall, Cambridge. Instructor Harvard University engineering, mathematics and experimental engineering, 1900-1905. In charge of courses in structural design, statics, descriptive geometry and stereotomy. Designed apparatus for engineering laboratories, 1902-1904. Asst. Sec. International Electrical Congress, 1904. Author of descriptive geometry for students of engineering. Engineer steam turbine department, Lynn Works, General Electric Co., responsible charge of steam research work. Charge of calculating department, 1905-1907. Present position: After May 20, 1907, will be in charge of Statistical Department, Westinghouse Church, Kerr & Co.

References: Richard H. Rice, Ira N. Hollis, S. B. Whiting, Sanford A. Moss, Lionel S. Marks, Arthur M. Greene, Jr.

SAMUEL GRAHAM NEILER, 1409 Manhattan Bldg., Chicago, Ill. Born: Erie, Pa., November, 1866. Education: Special in Mech. Eng. Course "M. I. T.," 1888. One year research at University of Minnesota. Drafting room: M. St. P. & S. St. M. Ry., as Asst. Mech. Eng. or "testing engineer," 1889-1890. Shop experience: T. H. Elec. Co., Lynn, Mass., 1890-1891, on expert course and as assistant in marine department. Other engineering work: Engineer in charge of Construction Dept. T. H. Elec. Co. (lighting), 1891-1892. Assistant engineer World Columbian Exposition, Chicago, 1892-1894. Member firm Pierce Richardson & Neiler, consulting and designing engineers 1894 to present time. Designed the mechanical portion of plant for the Kansas City Elec. Lt. Co., and power plant of Canton-Akron Interurban R. R., water works pumping plant, Hutchinson, Kans. Consulting engineer for Topeka Edison plant, Topeka, Kans.; purchased engines for new plant of Metropolitan St. Ry., Co., Kansas City, Mo. Designed water power plan and long distance transmission for Water Lt. & Power Co., Hot Springs, So. Dakota, and water works system same Co. Member Jury of Awards Steam Engines, St. Louis Exposition. Present position: Vice-Pres. and Treas. Pierce, Richardson & Neiler.

References: Calvin W. Rice, Frederick Sargent, E. C. Shankland, Chas. F. Foster, R. H. Pierce.

EDWIN NESBIT, Cleveland, Ohio. Born: Charleston, Ill., August, 1868. Education: B. S. University of Illinois, 1890. Drafting room: Mill department of Fraser & Chalmers, Chicago, 1890-1892. Matthiessen-Hegeler Zinc Co., LaSalle Ill., 1892-1901. United Zinc & Chemical Co., Iola, Kans., 1901-1903. Shop experience: University of Illinois 1886-1889. Vacations during same period in locomotive repair shop, Cloverleaf Railroad, Charleston, Ill. Other engineering work: Fraser & Chalmers, designing stamp mills, crushing machinery and furnaces, Matthiessen-Hegeler Zinc Co., designing zinc roasting machinery and zinc smelting furnaces. United Zinc & Chemical Co., designed, superintended erection of entire plant. The Grasselli Chemical Co., sole charge designing and erecting mechanical zinc roasting machinery, including circular roasters, power plant and pottery for zinc smelting plant. Present position: Zinc Engineer, Grasselli Chemical Co.

References: H. H. Hill, E. H. Whitlock, G. E. Merryweather, T. W. Capen, Wm. J. Reilly.

ALFRED NOBLE, 9 West 31 Street, New York, N. Y. Born: Livonia, Mich., 1844. Education: C. E. Michigan University, 1870. Other engineering work: Charge improvements St. Mary's Falls, Canal and St. Mary's River, 1870-1882, designed lock gates and operating machinery. Resident engineer Red River Bridge at Shreveport, La., 1882-1883. Gen. Asst. Engr. No. Pac. R. R., in charge of construction of several bridges, 1883-1886. Resident engineer Harlem R. (now Washington Bridge), N. Y. City; Ohio River Bridge at Cairo, Ill.; Mississippi River Bridge at Memphis, Tenn.; Asst. Chief Engineer Mississippi River Bridge at Alton, Ill.; Missouri River Bridge at Bellefontaine, Mo.; and Leavenworth, Mo. and Kansas, from 1886-1894. Member U. S. Nicaragua Canal Board 1895; U. S. Deep Water Ways Board, 1897-1900. Isthmian Canal Commission, 1899-1902. Panama Canal Board of Consulting Engineers, 1905. Chief Engineer East River Division P. N. Y. & L. I. R. R., 1902 to present time.

References: John Thomson, George Gibbs, Oberlin Smith, A. Sorge, Jr., E. C. Shankland, O. F. Nichols.

CARL GUSTAVE OSTEMAN, South Boston, Mass. Born: Forsby, Sweden, October, 1857. Education: Private Instruction. Apprentice: Motala Iron Works, Motala, Sweden, 1874-1878. Drafting room: Motala Iron Works, 1880-1881. Details and erecting drawings, Milwaukee, Sander Mfg. Co., Green Bay, Wis., 1896-1897. Designing S. A. Woods Machine Co., South Boston, Mass., designing, wood working machinery, 1903 to date. Shop experience: Motala Iron Works, Sweden, 1878-1880, later in charge of erecting small marine and hoisting engines. Atlantic Steam Engine Works, Brooklyn, N. Y., 1881-1884. Other engineering work: S. A. Woods Machine Co., general machinist, 1884; tool maker, 1886; tool-room foreman and designer of jigs and fixtures, 1887-1896. Designed the "Columbia" triple drum wood sanding machine at Milwaukee Sander Mfg. Co., 1896-1897. S. A. Woods Machine Co., charge of department, 1897; General Foreman, 1901; resigned 1903 to accept position as designer. Present position: Mechanical Engineer and Designer, S. A. Woods Machine Co.

References: F. F. Woods, David B. Carse, C. W. H. Blood, L. E. Harper, Wm. M. Whitney, Jno. B. Carse.

SHELDON F. PAYNE, Naugatuck, Conn. Born: Naugatuck, Conn., October, 1842. Trained as machinist with Gaylord Mfg. Co., Chicopee, Mass. Shop experience: Gaylord Mgf. Co., 1865-1878; master mechanic, 1873-1878; master mechanic, Western Lock Co., 1878-1883. Other engineering work: G. M. R. Shoe Co., Naugatuck, Conn., 1883 to present. Planned and installed machinery in plant, and also in United States Rubber Co., 1894, and new plant built in 1897. Present position: Master Mechanic, Goodyear M. R. Shoe Co.

References: F. B. Allen, Franklin Phillips, W. E. Crane, John C. Baker, G. S. Barnum.

WALTER AMBROSE PEARSON, Electrical Development of Ontario, Niagara Falls, Ont. Born: Putnam, Conn., July, 1869. Education: A. B., Tufts College, 1890. Other engineering work: June, 1890-1893 West End St. Ry. of Boston, Elect. Station construction work. Nov., 1890, Foreman in charge of Elect. Station Construction installed the Central and Cambridge Power Plants of that Company. Brooklyn City Ry. Co., Brooklyn, N. Y., supt. power plants, charge Elect. Construction South Power Plant and electrical design and construction Kent Av. and Ridgewood Power Plants; charge operation of these three plants after completion 1893-1895. 1895 Metropolitan St. Ry. Co. charge as resident engineer of construction of 146th St. plant and Lenox & Lexington Ave. elect. roads of that Company; operating engineer of both after construction was finished. 1898 E. E. of Co., charge of the elect. design and construction of the 25th and 96th Sts. and Kingsbridge Power plants, 10 sub-stations, and all the electrical surface roads in New York City. Charge of electrical operation of all plants and lines. 1905 Electrical Development Co., resident engineer, Niagara, charge mechanical and electrical construction Power Plant at Niagara Falls; 1906 appointed Chief Engineer of this Company and Toronto & Niagara Power Co. Member of A. I. E. E. Present position: Chief Engineer of Electrical Development Co., Ontario & Toronto & Niagara Power Co.

References: F. S. Pearson, Calvin W. Rice, Wm. Bancroft Potter, E. M. Hewlett, L. R. Pomeroy.

ERNEST BLACKMAN PERRY, Bay City, Mich. Born: Prairie Du Chien, Wis., December, 1868. Education: B. S., University of Michigan, 1889. M. E., University of Michigan, 1896. Drafting room: Industrial Works on cranes of various types, 1889-1890. Shop experience: Erecting Engineer for Industrial Works, 1891 and 1892. Other engineering work: Superintendent and engineer of Industrial Works, engaged in the manufacture of locomotive and wrecking cranes, also special railway appliances, 1892-1904. Present position: Since 1904 manager and engineer.

References: James H. Herron. M. E. Cooley, John R. Allen, Wm. L. Clements, D. F. Crawford.

FREDERICK PILLMORE, Syracuse, N. Y. Born: Westernville, N. Y., January, 1868. Education: M. E., Cornell, 1892. Drafting room: B. F. Sturtevant Co., Boston, Mass., 1892-1893. General Compressed Air Co., Rome, N. Y., 1894-1897. Rome Locomotive Mach. Works, Rome, N. Y., 1901-1903. Semet-Solvay Co., Syracuse, N. Y., 1903-1906. Shop experience: McIntosh-Seymour & Co., Auburn, N. Y.; 3 months, 1891. B. F. Sturtevant Co., Boston, Mass., Shop Inspector, 1893-1894. Other engineering work: Designed mechanical

equipment for P. & L. E. R. R. Station, Pittsburg, Pa., including heating and ventilating system complete. Designed and superintended installation of steam and electric plant for N. Y., N. H. & H. R. R. Back Bay Station, Boston, Mass. Superintended partial installations for Charleston Navy Yard, Charleston, Mass. American Hide and Leather Co., also Mass. Inst. of Technology, Boston. Superintended installation of refrigeration machinery Hotel Essex, Clarendon Hotel, Summerset Hotel, Westminster Hotel, Boston. While in charge of six or seven draftsman, Rome Locomotive & Machine Works, designed two series of Panhard type of touring cars; followed the experimental work, and construction through the shops. Recently in charge of a dozen draftsmen Semet-Solvay Co. Charge of the design of a miscellaneous line of iron and steel work for type of coke ovens, also foundations and track work, electrical equipment cars, coal levelers, coke pushers, etc., in connection with plants of The Milwaukee Gas & Coke Co., Milwaukee, Wis. By-products Coke Corporation, Chicago Ill. Pennsylvania Steel Co., Steelton, Pa., Lebanon, Pa. Also similar work for additional equipment for coke plants at Emsley, Ala., Tuscaloosa, Ala., Wheeling, W. Va., Dunbar, Pa., and Detroit, Mich. Present position: Foreman in Drawing room.

References: Albert W. Smith, Chas. L. Griffin, W. H. Blauvelt, W. E. Hopton, L. A. Zohe.

WILLIAM VON PHUL, New York City. Born: New Orleans, La., July, 1871. Education: B. S. and M. E. Tulane University, 1891-1893. Shop experience: Southern Electrical Mfg. & Supply Co. N. O., La. 1893-1894, general electrical and mechanical repairs and construction. Other engineering work: Two years teaching mechanical drawing, Tulane University. Supt. Power House, La. Electric Light Co., 1895. Supt. Station, Edison Elec. Co., 1896-1898; General Superintendent same company, 1898-1902. With Sargent & Lundy, 1892–1904, in charge design and construction power house of Cincinnati Gas & Electric Co., 1904–June, 1905, General Supt. Cincinnati Gas & Electric Co., June, 1905. Present position: Engineer with Ford, Bacon & Davis, New York City.

References: Frederick Sargent, Geo. W. Bacon, Harte Cooke, Alfred Raymond, F. D. Herbert, B. L. Baldwin.

JOHN PRIMROSE, New York. Born: Nova Scotia, May, 1873. Education: Four years McGill University, B. A. Sc., 1895. Apprentice: Carlton Place, Ontario. Canadian Pacific Ry., Repair shop, 1893-1894. Drafting room: Henry R. Worthington, water-works and layouts, 1895. Shop experience: Erecting and testing pumps and pumping engines, Henry R. Worthington. Other engineering ing works: In charge installing pumping engines, irrigation plants in Louisiana, Indiana. Present position: Since 1901 developing steam superheaters and their application to various types of boilers, and development of hydraulic rams. Chief Engineer, Power Specialty Company.

References: E. H. Foster, A. J. Caldwell, J. J. Brown, A. P. Boiler, Jr., Kenneth Torrance.

HAROLD MANDEVILLE PULSIFER, Chicago, Ill. Born: Auburn, N. Y., July, 1876. Education: One year special course in mechanics with Sibley College graduate. Apprentice: Buffalo Forge Company, Buffalo, N. Y., Testing block and erecting shop for high speed engines and blowers. Drafting room: Buffalo Forge Co., Buffalo, N. Y. Working drawings for engines, blowers and

heating apparatus and general drawings of their application B. F. Sturtevant Co., Philadelphia, heating and ventilating applications, 1898-1899. Shop experience: Buffalo Forge Co., 1896-1897. Other engineering work: Since 1899, contracting engineer for heating and ventilating and power equipment, B. F. Sturtevant Co., designed and executed equipments for public buildings and large industrial plant, Charleston, Illinois State Normal School. Heating and ventilating equipment, shops of New York Shipbuilding Co., heating. Shops of Louisville & Nashville Railroad Co., South Louisville, Ky., heating. Two years in design development and installation of apparatus for burning pulverized bituminous coal in rotary Portland cement kilns and annealing furnaces about five hundred rotary kilns and twenty-five annealing furnaces were successfully equipped. Western Manager, B. F. Sturtevant Co. Present position: President Automatic Sprinkler Construction Co., actively interested in fire protection engineering.

References: R. C. Carpenter, L. P. Breckenridge, H. C. Meyer, Jr., W. B. Snow, W. L. Bronaugh.

GEORGE WILLIAM RINK, 104 Claremont Ave., Jersey City, N. J. Born: New York City, Sept., 1875. Education: B. S. Cooper Union, 1897; M. E., 1906. Apprentice: Machinist trade Locomotive Works, Erie Railroad, Jersey City, N. J., 1892-1896; locomotive erection for 2½ years, machine operator 1½ years. Drafting room: Locomotive and Car Designing, 1899-1900, Northern Pacific Ry., St. Paul, Minn., Sept., 1900, to present date, Central Railroad of New Jersey, Jersey City, N. J. Shop work: Three years Erie R. R., 1896-1899, machinist on locomotive work, repairing and installing. Foreman of Machine shop, C. R. R. of N. J., Oct. and Nov., 1900. Other engineering work: Indicator and Road Tests of Locomotives, 1901-1904, C. R. R. of N. J. Steel coal car inspection Pittsburg, Feb. and March, 1901, for C. R. R. of N. J. Chief Draftsman, Motive Power Dept., June, 1902 to present date. Supervised the general design and details of various types of locomotives, freight and passenger cars. Instructor in mechanical drawing at Cooper Union, 1902-1903-1904. Present position: Chief Draftsman, Motive Power Dept., Central Railroad of N. J., Jersey City; general motive power designing as outlined above; instructor of apprentice school at Elizabethport shops.

References: Wm. McIntosh, Burton P. Flory, A. L. Bowman, Geo. W. Wildin, M. N. MacLaren, Louis A. Shepard.

OLIVER CROMWELL SPURLING, Chicago, Ill. Born: St. George's, Bermuda Islands, September, 1874. Education: Two years Bermuda private tuition. First Division Matriculation London University, England. First Division Senior Local Cambridge University, England. Held under Government control in Bermuda. Other engineering work: Western Electric Co., electrical wireman in Factory Engineers Office, New York, 1893-1896; Chicago, 1897-1898; New York, 1899-1901. Original design and responsible charge of steam and electric power plant of W. E. Co.'s London factory power plant, 1000 H. P. replacing obsolete equipment, 1902-1903-1904. Responsible charge of rebuilding entire cable plant buildings, London. Original design of W. E. Co.'s Chicago factory steam and electric power plant, additions including all mechanical transmission of power. Responsible charge of operating of W. E. Co's Chicago factory steam, electric, etc., plants, 1–3000 H. P. and 1–5000 H. P. plant, 1905-1906. Present

position: Asst. Plant Engineer, also Factory Engineer, Western Electric Co., Chicago, Ill.

References: H. M. Sage, D. A. Wallace, H. H. Wait, A. Sorge, Jr., W. S. Love.

HENRY SPOERRI, Falkenstrasse 21, Zurich, Switzerland. Born: Ruti, Switzerland, April, 1864. Education: Three years at Fribourg, Switzerland, College, 1877-1880. Two years at Technikum, Winterthur, 1882-1884; one year Polytechnikum, Zurich, 1887. Apprentice: Sulzer Brothers, Winterthur Engine works, 1880-1882, in the work shops. Drafting room: Sulzer Bros., Winterthur, 1885, Railroad Comp., Suiss Occidental Fribourg, 1888. Anglo-Swiss Condensed Milk Co. Cham, 1889. Railroad Comp. Jura Simplon Bern, 1891. Other engineering work: 1889-1890, establishing the plans for a condensing milk factory of the Anglo-Swiss Condensed Milk Co. at Cham, and managing the execution of the installations of machinery in the factory at Dixon, Ill., U. S. A.; 1891-1896, in the service of the Railroad Co. Jura Simplon as designer, controlling Engineer in Belgium, locomotive works, etc.; manager in the repair shop at Bienne, 1895-1896 Present position: 1896-1907, Mechanical Consulting Engineer, Spoerri & Co.

References: D. J. Lewis, Jr., By-Law B-2. Referred to Council with recommendation for membership.

CHARLES WATERMAN STONE, Schenectady, N. Y. Born: Providence, R. I., December, 1874. Education: Three and one-half years Kansas State University. Apprentice: Machinist and tool makers trade, W. S. Hill Elec. Co., New Bedford, Mass., 1896-1898. Machine work and tool making. Drafting room: W. S. Hill Elec. Co., New Bedford, Mass., 1898-1899, and General Electric Co., Schenectady, N. Y., 1899-1901. Shop experience: Franklin Elec. Co., Kansas City, Mo., 1893-1895. Other engineering work: Civil Engineer Interstate Consolidated Railway, Kansas City; made complete survey of elevated railway. Engineer on the New Bedford, Middleboro & Brocton Railway in Mass., the Mansfield & Norwood Street Railway. Present position: Lighting Eng'g Dept., General Electric Co. Since connection designed all the switching apparatus which has been adopted and used by the Government for all war vessels for last 8 years. Assisted in design of large vertical 2000 K.W. frequency changer sets, vertical rotary converters; also details in regard to electrical apparatus of all kinds. Design of large railway and lighting stations throughout the country; working out the mechanical details of the designs of the auxiliary apparatus, the location of same and the design of the buildings. Present work, design and development of different classes of apparatus, General Elec. Co. for large central station systems. Work involves the design of all apparatus from boilers to the lamps.

References: W. L. R. Emmet, J. W. Upp, H. G. Reist, H. H. Westinghouse, C. D. Haskins, John Riddell.

ARNOLD STUCKI, Pittsburg, Pa. Born: Blumenstein, Switzerland, October, 1862. Education: Three years at Meiringen, Switzerland; three years Munchenbuchsee, Switzerland, 1880. Apprentice: Superintending machinery and surveying land in the south, 1881-1886. Drafting room: Draftsman, designer in the Mech'l Engrs office Penna. R. R. Co., Altoona, Pa. In close touch, the respective shops, 1887-1900. Other engineering work: Designed the first flanging dies for boiler sheets in this country, details of the "Return system" of car heating, designed shops and machinery, charge of designing engines and freight cars, etc.

As mechanical Engineer of Pressed Steel Car Co., 1900-1903. Mechanical Engineer, Standard Steel Car Co., 1903-1905, developing steel cars; patentee of 40 or 50 original designs. Present position: Engineer, Pennsylvania Malleable Iron Co., Pittsburg, Pa.

References: Wm. O. Dunbar, Chester B. Albree, L. C. Moore, H. M. Hibbard, F. V. McMullin, F. S. Martin.

DAVID LONG SUMMEY, Waterbury, Conn. Born: Davison, Mich., March, 1875. Education: Three years Night High School. One and one-half years University of Illinois. Drafting room: United Gas Improvement Co., Philadelphia, Pa. Construction Dept. as erecting engineer and draftsman; Electric Power Stations, gas works, foundations, etc., 1900-1903. About one-third time in drawing room, balance outside in charge of erection. Other engineering work: Rodman in Eng. Corps, Buffalo Div. of Erie R. R., 1892-1895. Asst. engineer in Distribution Dept., Peoples Gas Light & Coke Co., Buffalo, N. Y., April to Sept., 1898. Charge of street main construction, Jenkintown & Cheltenham Gas Co., Jenkintown, Pa., Sept. to March, 1899. Charge of street main construction, Philadelphia, Suburban Gas Co., Darby, Pa., March to Nov., 1899. Supt. River Shore Gas Co., Riverton, N. J. Built works and Distribution System, Nov. to April, 1900. Asst. Supt. United Gas Imp. Co., Waterbury, Conn., in charge of Operating Depts., 1903-1906. Present position: Mechanical Engineer of Chase Rolling Mill Co., Waterbury, Conn.

References: J. M. Rusby, Geo. J. Roberts, E. S. Sanderson, W. H. Bristol, H. L. Thompson.

ALEXANDER TAYLOR, E. Pittsburg, Pa. Born: Glasgow, July, 1864. Shop experience: Westinghouse Elect. & Mfg. Co., 1888-1891. Other engineering work: Same Company. Storeroom and purchasing department, 1891-1897. Asst. supt. in charge of foundries from 1897-1902. Supt. of production, 1902-1905. Superintendent, 1905-1906. Present position: Manager of Works, 1906 to date. Westinghouse Elect. & Mfg. Co.

References: E. M. Herr, W. M. McFarland, H. L. Barton, E. S. McClelland, R. A. Smart.

T. KENNARD THOMSON, Park Row Bldg., New York City. Born: Buffalo, N. Y., April, 1864. Education: C. E. Toronto University, 1892. Apprentice: Six months each of 1883-1884-1885 on Canadian Pacific R. R. in the Rockies as Draftsman, Rodman, and Ass't Engineer. Drafting room: Dominion Bridge Co., Draftsman and Ass't. Engineer, 1880-1890. Other Engineering work: Engineer of Bridges for the Ohio extension of the Norfolk and Western R. R. Charge of the design and construction of 129 bridges including large bridge over the Ohio River, 1890-1891. Supt. of bridges for Chas. M. Jacobus, 1891-1892, Consulting Engr., Ass't Chief Engineer on the Blackwells Island Bridge, 2 piers completed to high water line, 1895. Principal Ass't Engineer, designed and built two elevated railroads in Brooklyn connecting Surface and Elevated railroads, 1898. Engineer, Arthur McMullen & Co., designed and supervised the sinking of 39 pneumatic caissons for the Commercial Cable Building on Broad Street, New York; water tight cellar, 16 feet under water, 1896. Engineer for Arthur McMullen & Co., designed and sank all sizes of pneumatic caissons, 1899-1906. Mutual

Life Insurance foundations, having a cellar floor 35 ft. under water. Present position: Consulting engineer.

References: John Thomson, A. L. Bowman, W. A. Cattell, Geo. B. Caldwell, Daniel E. Moran, H. B. Seaman, Augustus Smith.

ROBERT I. TODD, Indianapolis, Ind. Born: Lakewood, N. J., November, 1869. Education: E. E. Johns Hopkins University, 1893. Other engineering work: Supt. and Elec. Engineer City & Suburban Railway, Washington, D. C. Engineer American Air Power Co. and Metropolitan Street Ry. Co., New York, N. Y. General Master Mechanic, Consolidated Traction Co., Pittsburg, Pa. Engineer U. G. I., Co. Philadelphia, Pa. Second Vice President and General Manager, Cincinnati Traction Co., General Manager The Rhode Island Co., Providence. Present position: Vice-President and General Manager, Indianapolis Traction and Terminal Co.

References: Fred N. Bushnell, Thos. Elliott, Edwin Yawger, L. L. Brinsmade, F. C. Armstead.

BRUCE W. TRAYLOR, 118 Liberty St., New York City. Born: Mar., 1871, Huntsville, Texas. Apprentice: Shop S. E. Traylor, 1888-1892, general repair shop. Drafting room: Colorado Iron Works, Denver, Col. Traylor Engineering Company, New York. Shop experience: Colorado Iron Works, Denver, Col. Traylor Engineering Company 5 years; Allentown, Pa., 4 years. Other engineering work: Construction work, erecting mining, Reduction Plants, such as Stamp Mills, Concentrating Mills, Cyanide Plants, Smelting Works. Present position: Vice President Traylor Engineering Company. Design and equipment mining and smelting machinery.

References: Edw. J. Smith, T. H. Tracy, Geo. T. Ladd, H. B. Robinson, Earl C. Bacon.

GEORGE ROBINSON WADLEIGH, Bemis, Madison Co., Tenn. Born: New York, N. Y., February, 1875. Education: S. B., Inst. of Technology, 1897. Apprentice: Boston & Albany Locomotive Repair Shop, Boston, summer 1896. B. F. Sturtevant Co., Boston, 1898-1899. Somersworth Machine Co., Dover, N. H. Shop experience: Geo. Lawley & Sons, Corp., Boston, 1900. Other engineering work: Rodman and Asst. hydrographer, Nicaragua Canal Commission, 1897-1898. Since June, 1900, assistant supt. and asst. mgr. charge shops, power plant, construction work, and village. Asst. to engineer in charge original layout of 22,000 spindle cotton mill and mill village, general charge of plans purchase of material and construction of 32,000 spindle additions to original mill with preparatory machinery, power plant, etc., installation of village water works, electric light plant, plans and construction of 150 mill tenements, partial sewerage, laying out and grading 3 or 4 miles of streets, construction of street building, cotton warehouse, fire protection for entire plant, etc. Present position: Asst. Manager Jackson Fiber Co.

References: Chas H. Manning, Frank H. Ball, Peter Schwamb, Bert C. Ball, Wm. H. Collier.

CLIFTON W. WILDER, Brooklyn, N. Y. Born: Leominster, Mass., October, 1876. Education: S. B., Mass. Inst. of Tech., 1898. Drafting room: W. G. Norris & Co., Boston, 1898-1899, electric railroad construction., Edison Electric

Ill. Co., Boston, 1899-1900, steam and electrical construction. Other engineering work: Asst. to steam engineer International Paper Co., New York, 1900-1902. The Engineer Co., New York, 1902-1904. Supt. of construction and maintenance Asst. Engineer B. T. Babbitt, Inc., designing steam plant, 1904-1905. 1905 to date N. Y. C. Interborough Ry. Co. Present position: Asst. Engineer of construction N. Y. C. Interborough, Ry. Co.

References: E. S. Farwell, F. S. Tucker, H. L. Coburn, F. N. Dillon, Eugene W. Rutherford.

JOHN WILKINSON, Syracuse, N. Y. Born: Syracuse, N. Y., February, 1868. Education: M. E., Cornell University, 1899. Drafting room: Solvay Process Co., Syracuse, N. Y., May, to Jan., 1895. Shop experience: C. E. Stearns & Co., Syracuse, 1899-1900. Henry R. Worthington, Brooklyn, N. Y., 1890-1891. Other engineering work: Designer Syracuse Cycle Co., Syracuse, 1895-1899. Experimental automobile work, Syracuse, Jan., 1899-1902. Engineer in charge of automobile work, H. H. Franklin Mfg. Co., Syracuse, N. Y., Jan., 1902, to present time. Present position: Chief Engineer H. H. Franklin Mfg. Co., Syracuse.

References: Alex. T. Brown, W. B. Cogswell, John H. Barr, E. N. Trump, John E. Sweet.

LLEWELLYN WILLIAMS, Boston, Mass. Born: Jondaryan, Queensland, December, 1874. Education: Three years City and Guilds of London Technical Colleges. Apprentice: Port Glasgow, Scotland, Blackwood, & Gordon, Engineers and Shipbuilders, 1892-1897. Construction and design of marine engines and boilers. Drafting room: Asst. chief draftsman Linde British Refrigeration Co., London, 2 years. Chief Draftsman Linde Company of Canada, and manager American Linde Co., 2 years. Shop experience: Erecting engineer Linde Refrigeration Co., London, 1 year. Other engineering work: Superintended construction of new vessels for United Fruit Company, Belfast, Ireland. Design and equipment of refrigeration machinery and system for six vessels carrying perishible banana cargoes. Patentee and inventor of system now used for this purpose on ships of United Fruit Company. Present position: Supt. of Refrigeration, United Fruit Co., Boston, Mass.

References: Henry Torrance, Jr., D. S. Jacobus, W. D. Forbes, John E. Starr, G. T. Voorhees.

ROYDON VINCENT WRIGHT, East Orange, N. J. Born: Red Wing, Minn., October, 1876. Education: M. E., University of Minn., 1898. Apprentice: Machinists' apprentice Chicago, Milwaukee & St. Paul Ry., 1898-1899, erecting floor of the locomotive repair shop. Drafting room: Chicago, Great Western Ry., St. Paul, Minn. About six months special apprentice in the motive power department, assigned to drawing room duties, St. Paul. Was then placed in charge of the drawing room at St. Paul, reporting to the superintendent of motive power, 1898-1899. Other engineering work: Mechanical Engineer, Pittsburg & Lake Erie Railroad at Pittsburg, Pa., when locomotive repair shops were designed and built. Had considerable special work in connection with these shops, notable design of application of individual motors to both old and new machine tools, 1901-1904. In July, 1904, appointed Associate Editor of the American Engineer & Railroad Journal, and in Oct., 1905, succeeded to the managing editorship of

that Journal. Present position: Managing Editor of the American Engineer and Railroad Journal.

References: H. G. Hammett, Dr. W. F. M. Goss, Harrington, Emerson, H. H. Vaughan, G. M. Basford, Prof. H. Wade, Hibbard F. M. Whyte.

FOR PROMOTION TO FULL MEMBERSHIP

G. NORWOOD COMLY, Syracuse, N. Y. Born: Philadelphia, Pa., December, 1874. Education: B.S. in M. E. University of Penn., June 1897. M. E., University of Penn., June, 1904. Apprentice, Chambers Bros. Co., Philadelphia, Pa., 1897–1899. Drafting-room, Solvay Process Co., 1899 to present time. Other engineering work: Responsible charge of the designs for the construction of a 3300 horse-power boiler plant with 500-ton coal bin and conveyor system. 500 ton coal bin, conveyor system and details of piping for a 3600 horse-power boiler plant. 1000-ton lime plant for burning stone and slacking lime—lime kilns, motor-driven continuous mechanical discharge and forced draft; continuous lime slackers; conveyor system for handling stone coke and lime; mechanical measuring and feeding machinery; collecting and washing of gas from kilns and distributing it through 48″ mains to compressors at various points. Improved feeding mechanism for rotary furnaces, gas and steam mains. Present Position: Draftsman, Solvay Process Co., in charge of a squad of from six to ten men.

References: George N. Comly, E. N. Trump, W. H. Blauvelt, H. W. Spangler, A. R. Gillis.

Elected a Junior Member, 1905.

WILLIAM DUANE ENNIS, Schenectady, N. Y. Born: Wortendyke, N. J., January, 1877. Education: M. E., Stevens Institute of Technology, 1897. Apprentice: Rogers Locomotive Company, Paterson, N. J. (machinist), 1892–1893—Vise, Lathe and erecting floor. Drafting-room: Passaic Rolling Mill Co., Paterson, N. J., 1895–1896; Structural Steel. Other engineering work: Consolidation Gas Co., of N. J., Long Branch, N. J., electric central station experience, 1897–1898. Walworth Cons. & Supply Co., Boston, Mass., construction of electric plants, Worcester County Court House, Commonwealth Hotel, Worcester, Mass., U. S. Mortar Battery, Winthrop, Mass. and representative steam piping installations throughout New England, 1898–1900. Tower & Wallace, New York, design of brick chimneys for Oxford Paper Co., Toronto Paper Mfg. Co., and of representative piping installations, various, 1900–1901. Traveled as engineer for various Rockefeller interests, including; Everett Pulp & Paper Co., Everett, Wash., supervision of plant, construction and repairs. Puget Sound Reduction Co., Everett, Wash., design of additions to lead smelting plant. Monte Cristo Rwy. Co., Everett, Wash., reporting on locomotive performance. American Linseed Co., New York, power plant and mill buildings, including submarine foundations as Port Richmond, N. Y., power transmissions at Toledo, Ohio, heating at Chicago, Ill., and for two years in charge of operation of Eastern mills, assistant to President, 1901–1905. Present Position: American Locomotive Co.

References: W. L. Reid, A. Riesenberger, Paul Doty, Arthur C. Walworth, William T. English, Jos. H. Wallace, D. S. Jacobus.

HARRY VERCOE HAIGHT, Sherbrooke, Que. Born: Sparta, Elgin Co., Ontario, Can. Education: B. A. Sc. University of Toronto, 1897. Elected Junior Member, 1899. Drafting-room: Canadian Rand Drill Co., Salesman in Nova Scotia, October 1897–1899. New York, design and construction, large special air compressors for British Columbia. Other engineering work: Appointed Chief Engineer of Canadian Rand Drill Co., July 1900, designing air compressors, rock drills, coal cutters, compressed air locomotives, haulage plants, and pneumatic tools. Made general plan for new buildings and extensions. Present position: Chief Engineer, Canadian Rand Drill Co.

References: F. A. Halsey, Wm. Prellwitz, H. V. Conrad, F. W. Parsons, John S. Whyte, A. W. Patterson, Jr.

H. L. KUTTER, Hamilton, Ohio. Born: Linden, Germany, July, 1872. Education: Royal Gymnasium, Hirchberg, Germany. Apprentice: Bruderhaus, Reuttlingen, Württemberg, Germany, Paper Mill Machinery, 1889 (about.) Drafting room: Bruderhaus, Reuttlingen, Eichberger Papier-fabriken, Remington Paper Co., Watertown, N. Y., The Black-Clawson Co., Hamilton, Ohio, Chief draftsman. Shop experience: Michigan Sulphite Fibre Co., Port Huron, Mich., as foreman and engineer. Other engineering work: Mechanical engineer, Lake Superior Power Co., Sault Ste Marie, Ontario. Drawings and construction, 10,000 H. P. waterpower plant and ground wood pulp. Present position: Sales manager and engineer, The Black Clawson Co., Hamilton. Designing, estimating, specifying and selling paper mill machinery.

References: J. W. See, Jas. R. Cullen, A. C. Rice, A. L. DeLeeuw, Geo. T. Reiss.

Elected a Junior Member, 1902.

GERHARDT JOHN PATITZ, P. Schoenhofen Brewing Co., Chicago, Ill. Born: Germany, October, 1876. Education: 3 years Royal Institute for Commerce and Technics, Dresden, 1893. Apprentice: Chi. Mil. & St. Paul Ry. Co., Milwaukee, Wis., machine shop, 1893–1894. Drafting room: Pabst Brewing Co., Milwaukee, Wis., 1894–96; Vilter Mfg. Co., Milwaukee, Wis., 1896–1904. Shop experience: Chicago, Milwaukee, and St. Paul, 1893–94. Other engineering work: Vilter Mfg. Co., 1896–1904, efficiency tests, both electrical and mechanical indicator practice, erection superintendence on ice plants, all kinds of refrigerating plants and breweries. Present Position: Master mechanic and chief engineer, 1904 to the present time, P. Schoenhofen Brewery Co., Chicago, superintendence of entire technical and electrical department, drawing room, purchasing and testing, also consulting engineer for Schoenhofen Investment Co.

References: Fred W. Wolf, J. F. Max Patitz, W. G. Starkweather, Charles Elmes, R. A. Widdicombe, M. A. Beck.

Elected a Junior, 1900.

RUSSELL WELLESLEY STOVEL, New York City. Born: Toronto, Ontario, Can., Feb. 1877. Education: B.A.Sc. McGill, 1897. M.Sc. McGill, 1900. Other engineering work: Wireman with Pittsburg & Lake Erie Railway, 1898. With Westinghouse, Church, Kerr & Co. as Field Superintendent for Mechanical and Electrical equipment, P. & L. E. Ry. Terminal, Pittsburg, 1899–1900. Electrical Engineer, P. & L. E. Ry., 1900–1901. With W. C. K. & Co. in field charge of design and construction for mechanical and electrical equipment, McKees

Rocks Shops, P. & L. E. Ry., Pittsburg, 1902–1904. With W. C. K. & Co. in office charge of construction for sub-station buildings and equipment, Long Island Railroad Electrification, 1904–1905. With W. C. K. & Co. in charge of design and construction for mechanical and electrical equipment of Wabash Terminal, Pittsburg, 1906. Present position: Engineer, Westinghouse, Church, Kerr & Co.

References: Albert W. Smith, Walter C. Kerr, Henry R. Kent, George B. Caldwell, George B. Preston.

Elected a Junior, 1902.

BENJAMIN FRANKLIN WOOD, Altoona, Pa. Born: Farmington, Ark., February, 1872. Education: B.E.E. University of Arkansas, 1893. Other engineering work: Complete Electric Construction Co., 1894; Engineer and superintendent with same company, 1895, charge of all construction work, including installations of small generating plants, wiring of buildings and track and overhead construction for street railways. Resigned, 1897. J. J. de Kinder, Philadelphia, design of power stations; testing of boiler plants; conducted a series of coal tests for State Line and Sullivan Railroad Co., Draftsman Pennsylvania R. R. Co., 1898. Assistant engineer, 1899; Assistant engineer, Motive Power Dept., P. R. R. Co.

References: J. M. Whitman, C. W. Hunt, Theo. N. Ely, M. W. Sewall, Wm. Schwanhauser, C. A. Lindstrom.

Elected a Junior, 1897.

TO BE VOTED FOR AS ASSOCIATES

THEODORE P. ARTAUD, 111 Broadway, New York City. Born: Jackson, Miss., April, 1876. Education: A.B. & M.S. Harvard Univ. 1895–1897. Apprentice: G. E. W. E. Companies, Carey St. R. R., Baltimore, Md. Shop experience: During the summer months of collegiate course, Steelton Iron Works, Sparrows Point, Baltimore, Md. Other engineering work: U. S. Army, 21st Infantry, 1898–1900. Taught mathematics and Drawing, University School, Baltimore, Md., 1900–1902. From 1903 to present time with Hudson Companies in various capacities. Present position: Purchasing Agent, Hudson Company.

References: Frank J. Logan, George A. Doughty, A. R. Baylis, John D. Logan, Paul H. Grimm.

FRANK BISHOP, 136 La Porte Ave., South Bend, Ind. Born: Carthage, Mo., Oct., 1877. Education: B. S. in M. E. Purdue University, 1903. Drafting room: Westinghouse Air Brake Co., 1903–1904, Wilmerding, Pa., Singer Mfg. Co., 1906–1907, So. Bend, Ind. Shop experience: Westinghouse Air Brake Co., Wilmerding, Pa., June-Aug., 1903. Other engineering work: Westinghouse Air Brake Co., Wilmerding, Pa., Testing Dept., charge of a special train for testing triple valves. Asst. Foreman, Assembling Dept., 1905. Charge Machine Shop C. W. Hunt Co., West New Brighton, N. Y., 1906. Master Mechanic Singer Mfg. Co., Case Factory as draftsman and designer. Present position: Since Jan., 1907, charge of Machine Shop and Millwright Dept., Singer Mfg. Co., Case Factory.

References: W. J. Rickey, R. W. Emerson, W. F. M. Goss, M. J. Golden, J. D. Hoffman.

CLAUDE E. COX, Indianapolis, Ind. Born: Libertyville, Indiana, April, 1879. Education: M.E. Rose Polytechnic Institute, 1906. Other engineering work: With Standard Wheel Co., in charge Automobile Department, charge of designing and production as superintendent, later manager with complete charge, 1902. Present position: Standard Wheel Company, now being operated as Overland Automobile Company. Partner and general manager.

References: H. J. Horstmann, Thomas Gray, F. C. Wagner, M. W. Mix, Jesse Warrington, J. R. Whittemore.

ROBERT CRAIG, Minneapolis, Minn. Born: Galt, Ontario, Canada, May, 1876. Education: M.E. Minnesota, 1897. Shop experience: Vacation work while attending U. of M. devoted to gasoline engine repairing and erecting. After leaving college spent year 1897–1898 testing gasoline and steam engines in factories of Pierce Engine Co., and Racine Hardware Co., Racine, Wis. Other engineering work: C. D. Holbrook & Co., Minneapolis, Minn. repairing and installing gasoline engines, 1898–1899. Otto Gas Engine Works, Minneapolis, as erecting engineering and salesman, 1899–1900. Summer of 1900 spent in Europe studying gas and oil engines in factories and at Paris Exposition. Fairbanks, Morse & Co., St. Paul, Minn., in charge of gas engine sales and installing, 1900–1903. A. F. Chase & Co., Minneapolis, 1903–1905. Present position: Since April, 1905, have been representing the Olds Gas Power Co., Lansing, Mich., and the American Grain Meter Co., Springfield, Ohio, having entire charge of sales and erecting of their products in several states. Manufacturers' Agent.

References: H. Wade Hibbard, H. E. Smith, J. J. Flather, Louis Bendit, F. G. Hobart.

ARCHER DAVIDSON, Atlanta, Ga. Born: Farmville, Va., February, 1881. Education: B.S. Va. Polytechnic Inst., 1902. Apprentice: 3 months, Clelland & Co., Lynchburg, Va., 1899, power and steam heating system Virginia State Female Normal School. Shop experience: Machinist, Westinghouse Machine Co., July to Sept., 1902. Asst. Foreman in steam turbine erecting and testing dept. Westinghouse Machine Co. Sept., 1902 to April, 1903. Other engineering work: Erecting Engineer under direction Westinghouse, Church, Kerr & Co., having charge of installation engine room equipment extension power plant at S. D. Warren Paper Co., and new plant at Saco & Pettee Machine Co., Biddeford, Me., 1903. Westinghouse Machine Co. Erecting Engineer erecting steam turbine units and single acting engine units. During this time connected with the installations of about twenty turbine units for plants furnishing power for cotton mills, railway, lighting and industrial purposes. Present position: District Engineer Atlanta, The Westinghouse Machine Co.

References: L. S. Randolph, Francis Hodgkinson, F. S. Tucker, F. C. Armstead, J. Henry Klinck.

RALPH WOOLMAN DEACON, Chrome, N. J. Born: Mount Holly, N. J. April, 1878. Education: B.S. in M.E. University of Pennsylvania, 1898. Shop experience: Philadelphia. Wm. Sellers & Co., 1899–1900. Penna. Iron Works, 1900–1901. Outside construction work, Balto. Office of General Elect. Co., 1898–99. Other engineering work: Baltimore Copper S. & R. Co., Baltimore, Md., 1901–1905. Mechanical Engineer and foreman of bluestone, cupola and

smelting departments. Jas. Barker's Iron Foundry and Machine Works, Philadelphia, Pa., supt. of plant, 1905–1906. Penna. Glass Sand Co., Asst. to General Manager, April, 1906 to Nov. 1906. Present position: Asst. Superintendent Chrome Works of U. S. Metals Refining Co.

References: Henry W. Spangler, Wm. H. Peirce, Wm. W. Nichols, Geo. N. Comley, Stanley G. Flagg, Arthur M. Greene, Jr.

H. EDW. DUNKLE, Syracuse, N. Y. Born: Philipsburg, Pa., July, 1872. Education: B.S. & M.E. Pennsylvania State College, 1893–1896. Drafting room: Amer. Bridge Co., Ambridge, Pa., transmission and structural work, 1904–1905. Semet-Solvay Company, Syracuse, N. Y. general engineering, 1905. Other engineering work: Four summer vacations of 2½ months each on detail drawing work hydraulic machinery for steel mills, operating platform for rolling mill, crane and elevators. Instructor in mechanical engineering, The Pa. State College, from 1893–1904. Present position: Drafting Semet Solvay Co.

References: C. L. Griffin, B. A. Lenfest, W. E. Hopton, L. E. Reber, W. M. Towle.

ALFRED LYON FITCH, Chicago, Ill. Born: Fowler, Ill., June, 1862. Education: S. B. Mass. Inst. of Tech., 1884. Apprentice: Frederick Tudor, Steam Fitting, 1884. Drafting-room: Charles F. Elmes, Chicago, 1887–1889. Other engineering work: Instructor in Mech. Eng. Laboratory, Mass. Inst. Tech. 1885–1887. Supt. E. T. Harris Co., 1899–1891. Sec'y and Treas. American Architectural, Iron & Brass Works, Chicago, 1891–1895. M. J. Fitch Paper Co., 1895–1898. Engineer in Construction Dept. Swift & Co., 1898–1902. Western Electric Co., Tool Drafting Dept. Chicago, 1902 to date. During intervals in above, was in engineering work with Sargent & Lundy, R. W. Hunt, and Armour & Co., Chicago. Present position: Supt. in charge of Special Machinery in Tool Drafting Dept. Western Electric Co.

References: Geo. M. Brill, Gaetano Lanza, David Lofts, C. B. Appleton, B. R. T. Collins.

GEORGE HERBERT GIBSON, New York City. Born: Wayne, Mich., March, 1876. Education: B.S. University of Michigan, 1899. Apprentice: Westinghouse Elec. & Mfg. Co., April to July, 1899. Other engineering work: Asst. Editor of "Engineering News," 1899–1901. Editor Westinghouse Company's Pubishing Dept., 1901–1903. Advertising Manager B. F. Sturtevant Co., 1903. Manager Dept. of Publicity International Steam Pump Co., New York, N. Y., 1903–1905. Advertising Advisor Green Fuel Economizer Co. Harrison Safety Boiler Works; Strong, Carlisle & Hammond, Lagonda Mfg. Co., Joyce Cridland Co., Diamond Chain Co., Battery Supplies Co., Shultz Belting Co. Patented direct current dynamo in U. S. and England, assigned to Westinghouse Elec. & Mfg. Co., Patented magnetics. Variable speed drive assigned to Westinghouse Elec. & Mfg. Co.

References: Walter M. McFarland, R. C. Stevens, Wm. Kent, Charles Whiting Baker, Bert L. Baldwin.

Elected Junior member, 1900.

RAY D. LILLIBRIDGE, New York. Born: Hinkley, Minn., August, 1878. Drafting-room: Designed and constructed various improvements to different

automobiles; also disassembling and assembling of such machines. Other engineering work: Writer of technical trade literature for Otis Elevator Company, Stanley Electric Mfg. Co., The Engineer Co., Platt Iron Works Co., C. W. Hunt Co., Link Belt Engineering Co., Wellman-Seaver-Morgan Co. Present position: Advertising manager for several of above concerns and President Rees Co.

References: Chas. Wallace Hunt, S. T. Wellman, James M. Dodge, Albert Spies, H. L. Aldrich.

FRANK LEWIS MILLER, Pine Grove, West Virginia. Born: June, 1873, Lancaster, Ohio. Education: 3 years Lippincot Correspondence of Philadelphia and American School of Correspondence, Chicago, Ill. Apprentice: Lancaster, Ohio. Eagle machine Co., 1889–1902. Drafting room: J. H. Montgomery Machine Co., Denver, Col., 1898–1900. Shop experience: F. M. Davis Iron Works, builders of machinery Denver, Colorado, 1897–1898. Other engineering work: Assistant erecting and running engineer at Lancaster Gas and Elec. Co., Lancaster, Ohio 1892–1895 Charge of power and electric department Columbus State Hospital, 1895–1897. Chief engineer Central Ohio Natural Gas Co., Lancaster, Ohio, 1900–1903. Present position: Chief Engineer in complete charge of gas compressing stations of Hope Natural Gas Co.

References: E. C. Lufkin, Chas. L. Newcomb, S. B. Dougherty, J. E. Aue, E. C. Sornborger, C. N. Scott.

ELLIS F. MUTHER, 114 Liberty St., New York City. Born: Chicago, Ill., February, 1879. Education: 2 years High School, Lewis Inst., Chicago. Apprentice: Crane Co., Chicago, Ill., 1895–1899. Union Special Sewing Mch. Co., Brass working tools and general fine tool making for sewing machine parts. Drafting room: Special fixtures, machine and tools for Union S. S. M. Co., Chicago, 1898–1899. Shop experience: Crane Co., 1895–1898. Tool making Special Sewing Wachine Co., Chicago, 1898–1899. Other engineering work: Marshall & Huschart Mchy. Co., 1901–1902, Cincinnati, Ohio. Gisholt Mch. Co., 1902 to date, estimating time and cost of production, designing of special tools and methods of operation, routing of work and the general use of Turret Lathes, Vertical and Horizontal Boring Mills, etc. Present position: Industrial Engineer with Gisholt Machine Co.

References: C. L. Libby, R. K. LeBlond, F. L. Eberhardt, C. E. DePuy, A. Marshall, C. A. Johnson.

DAVID MOFFAT MYERS, 309 W. 70th St., New York City. Born: Owasco, N. Y., January, 1879. Education: Columbia University, M. E., 1901. Apprentice: David Moffat Co., 1901–1902. Drawing room: M. E. U. S. Leather Co., 1902–1906. Shop experience: Great deal of testing to determine economy of operation in the many plants of the company and recommended improvements to produce fuel and operating economies, exhaustive investigation of wet tan burning, designed and patented stoker furnace which was adopted and used by the company for that purpose; designed their standard furnace for burning mixture of tan and coal. Other engineering work: Testing and investigation of gas engines. Superintended construction of two modern boiler plants. Present position: Mechanical engineering relating principally to power plant economy.

References: F. R. Hutton, D. S. Jacobus, Chas. E. Lucke, Morris M. Green, Chas. P. Benns.

JOHN HARVEY ROSE, Bradford, Pa. Born: Johnstown, Pa., 1865. Education: High School, three years private tuition mechanical engineering and drafting. Apprentice: Geo. W. Rose general machine shop. Supervision of work done at shop. Other engineering work: Designed gearless pumping jack for oil and water wells, reversible gear for gas engines, casing spear with release wedges. Developed and assisted in perfecting the Dresser pipe coupling. Designing and erecting complete power and lighting plants. Installed the first complete central station in which large gas engines displaced steam. Complete charge of erecting plant of Bradford Electric Light & Power Co. Rebuilt station, installing Westinghouse gas engines, effecting a saving in fuel alone of 75 per cent. Specific charge of plan of station, erecting work, etc. Present position: Secretary and general manager of Bradford Electric Light & Power Co.

References: E. E. Keller, E. S. McCelland, H. E. Longwell, Wm. P. Flint, Wm. A. Bole.

FREDERICK ALBERT SCHROEDER, Westmont, Johnston, Pa. Born: Milwaukee, Wis., Nov., 1871. University of Wisconsin, 4 years. B. S. E. E., 1899. Apprentice: Chicago, Milwaukee St. Paul R. R. and E. P. Allis Company, 1891–1895. Locomotives, machine and bench work, all special machinery, hoisting engines and pumping engines. Drafting room: Chicago, Milwaukee & St. Paul R. R. Co., Partly Shop and Drawing Room, 1899–1900. Chief Draftsman, Motive Power Dept. Rolling Mill Draftsman, 1900–1901. Assistant, in charge Drawing Room Engineering Dept. Cambria Steel Co., 1901–1904. Other Engineering work: Locomotive testing, designing power plant, C. M. & St. P. R. R. Co. Asst. Supt. Roll Turning Department, Cambria Steel Co., 1904 to date. Present position: Ass't Supt. Roll Dept. Cambria Steel Co., Johnstown, Pa. Consists of designing of all classes of rolls, Superintendence of Shop. Consulting work.

References: Joseph Morgan, Jr., James H. Geer, O. B. Zimmerman, J. H. Herron, C. W. Whiting, E. V. Wurtz.

GRANT BATCHELDER SHIPLEY, Milwaukee, Wis. Born: Coulterville, California, April, 1880. Education: 3½ years Humboldt Evening High School, San Francisco, Cal. Apprentice: On valve gear work, indicating engines on steamers, stationary engines, and marine engines, some experience taking trial trip data, ocean going steamers, ferry boats and tow-boats. Drafting room: Western Sugar Refinery, San Francisco, Machinist, 1897–1900. Sugar machinery boilers, condensers, economizers, engines. Risdon Iron Works, San Francisco, 1900–1903. Draftsman and designer, looking after repair and new work. Chief draftsman, Union Iron Works, 1903–1904. Other engineering work: Original design, Heine water tube, Scotch & Galloway boilers, Corliss engines, air compressers, gold and silver mills. Present position: Allis-Chalmers Co., 1905 to date, Salesman and Engineer.

References: Thomas W. Capen, W. E Dodds, Max Rotter, W. G. Starkweather, E. W. Linquist.

J. HENRY SIRICH, Jr., 6 East Forty-fifth St., New York. Born: Baltimore, Md., April, 1881. Education: Baltimore Poltechnic Inst., graduated 1898. Apprentice: Robert Poole & Son Co., Baltimore, Md. 1898. Drafting room: Draughtsman, designer, General Eng. Work, Robert Poole & Son Co., 1900–

1903. Mann & Co., May to Dec., 1904. American Bridge Co., U. S. Steel Cor., Jan. to Mar., 1905, Ambridge, Pa. Shop experience: R. Poole & Son Co., 1898–1900. Engineering & Machine Co., Balto., Md. Westinghouse Machine Co., Turbine Testing Dept., East Pittsburg, Pa., March to July, 1905. Erecting Eng., July-Sept., 1905. Foreman, Turbine Testing Dept , Sept., 1905 to Feb., 1906. Trouble Foreman, Turbine Erect. Dept., New York Dist., Feb., 1906 to present time. Other engineering work: Marine engineer with Atlantic Transport Line, 1903–1904. 5th Eng. S.S. "Mississippi," April-July, 1903; Sept-Oct., 1903. Asst. Eng S.S. "Minnetonka," July-Sept., 1903. 4th Eng. S.S. "Mississippi," Oct., 1903; April, 1904. Full charge of regular watch. Hold 2d Asst. Eng. License, Ocean Condensing Steamers. Past year full charge all trouble and repair work on turbines. Present position: Gen'l Trouble Eng., Turbine Erecting Dept., New York Dist., for Westinghouse Machine Co.

References: Henry L. Barton, Francis Hodgkinson, P. O. Keilholtz, Fred N. Bushnell, L. L. Brinsmade.

CHARLES HENRY SPEER, Oakland Ave., West New Brighton, N. Y. Born: Richmond, Ind., December, 1869. Education: St. Louis Manual Training School. One year Washington University. Apprentice: St. Louis Iron & Machine Works, 1891–1895; Corliss engines, hydraulic brick presses and general repair work. Drafting room: American Brake Co., 1895–1899. 1902–1903, Cambria Steel Co., Johnstown, Pa., on general run of rolling mill work. 1903–1905, Lackawanna Steel Co., Buffalo, N. Y., head draftsman in rolling mill division. Charge over the rolling mill division of the engineering dept., which division comprised the Slabbing Mill, Plate Mill, and Blooming Mill; work covered the piles to the finished mills; also repairs and improvements for Rail Mill No. 1 and the Bessemer Steel Works. Oct., 1905 to date, Milliken Bros., Inc. Steel Works, Staten Island, N. Y. Shop experience: 1899–1900, Leighton & Howard Steel Co., St. Louis, Mo. General Master Mechanic; erected all the machinery of their new East St. Louis plant and superintended the construction of about half the buildings and all of the five open hearth furnaces. 1900–1902, Mechanical engineer with same Co. Present position: Chief draftsman, Milliken Bros., general rolling mill design.

References: Geo. H. Waters, Charles F. Smith, C. L. Taylor, Chas. B. Rearick, Louis Bendit.

WALTER OWEN TEAGUE, Lafayette, Ind. Born: Lowell, Mass., March, 1879. Education: S.B. Mass. Institute Technology, 1902. Drafting room: Draftsman, New York Shipbuilding Co., Camden, N. J., 1903–1904. Estimator, Fore River Ship Building Co., Quincy, Mass., Feb. to Sept., 1904. Shop experience: Pattern work. structural steel work, erection of piping, setting up engines, machine work, Sept., 1902 to March, 1903. Steam turbine testing, General Electric Co., West Lynn, Mass. April to July, 1905. Other engineering work: Lecturer and Mechanical Engineering, School of Mining, Queens University, Kingston, Ontario, Canada, 1904–1905. Assistant professor experimental engineering, charge steam engine, gas engine, hydraulic, locomotive and railroad testing laboratories, Purdue University. Present position: Assistant professor of experimental engineering, Purdue University.

References: W. F. M. Goss, E. F. Miller, M. J. Golden, G. Lanza, L. V. Ludy.

CICERO BAILEY VEAL, Purdue University, Lafayette, Ind. Born: Greenfolk, Ind., February, 1880. Education: B. S., Purdue University, 1902. Drafting room: Western Electric Co., Chicago, Ill., 1903. Rockwood Mfg. Co., Indianapolis, Ind., 1905–1906. Shop experience: Garr, Scott & Co., Richmond, Ind. Other engineering work: Field Expert, McCormick Harvester Co., 1899–1900, charge of construction work, Economy, Ind., 1902. Asst. in machine design, Purdue University, 1902–1904. Expert demonstrator of exhibit of colleges of agriculture and mechanic arts, and experiment stations, Universal Exposition, St. Louis, Mo., 1904. Instructor in machine design, Purdue Univ., 1904–1905. In charge of design of special machinery and production engineering work for Rockwood Mfg. Co , Indianapolis, Ind., 1905–1906. Present position: Instructor in machine design, Purdue University.

References: W. F. M. Goss, M. J. Golden, L. V. Ludy, J. D. Hoffman, G. A. Young.

FOR PROMOTION TO ASSOCIATE GRADE

E. W. NICKLIN, Atlas Engine Works, Indianapolis, Ind. Born; Woodstock, Ont., Canada, June, 1876. Education: Y. M. C. A. Institute, Detroit, Mich. Shop experience: Arthur Colton Machine Co., 1890–1892. Other engineering work: Detroit Switchboard & Tel. Cons. Co., Detroit, Mich., nine months. Fisher Mfg. Co., Detroit. Mich., eight months. Yale Mfg. Co , Albion. Mich., nine months. Mechanical draftsman, charge of department; Morton Mfg. Co., Muskegon, Mich. Three years as assistant engineer Detroit Water Board. Two years as manager appraisal department for Field, Hinchman & Smith; charge of their Detroit office and work in this locality, 18 months. Present position: Mechanical Engineer, The Arbuckle-Ryan Co. Since Dec., 1906, sales department Atlas Engine Works.

References: Millard T. Conklin, Theo. H. Hinchman, Wm. J. Keep, Frederick H. Mason, Mark M. Sibley, E. S. Reid.

Elected Junior Member, 1900.

PAUL C. VAN ZANDT, Chicago, Ill. Born: River Forest, Ill., May, 1878. Education: B. S. M. E., Purdue University, 1899. Drafting room: 1896–1907, Aermotor Co. 1899–1900 Gates Iron Works, detailing machinery, design of machinery, mining plants, crushing plants, smelters, cement plants, etc. Shop experience: one half year with Aermotor Co. Other engineering work: With Allis-Chalmers Co., since formation of that concern in 1901. Cost Dept., Estimating Dept., and Selling Dept., 1902–1903, in Salt Lake City as selling engineer in cement dept. Special engineering work in design of cement plants and portions of plants in design of cement machinery, especially large kilns. Washington Portland Cement Co., Baker, Wash. El Almendares Fabrica de Cemento Havana. Present position: Special Salesman and Engineer with Allis-Chalmers Co.

References: T. W. Capen, H. A. Allen, Norman D. Fraser, E. E. Hanna, Herman Unzicker, M. Wm. E. Dodds.

Elected a Junior Member, 1900.

TO BE VOTED FOR AS JUNIORS

HOWARD LEE ANDERSON, 1224 Frick Bldg., Pittsburg, Pa. Born: Chicago, Ill., April, 1882. Education: B. S., Purdue University, 1902. Drafting room: Four years designing machinery Sullivan Machinery Co., Chicago Works, 1902–1906. Shop experience: In galvanized iron shop, Fraser & Chalmers, Chicago, July to Sept., 1899, and July to Sept., 1900. In small machinery shop. July to Sept., 1901, Chicago, Ill. Present position: Engineering Dept., American Sheet and Tin Plate Co.

References: John J. Muir, W. F. M. Goss, L. V. Ludy, J. D. Hoffman.

WILLIAM HENRY CARDEN, Oglesby, Ill. Born: Chicago, Ill., January, 1882. Education: 2 years Lewis Institute, Chicago; 3 years Cornell University. Drafting room: Western Electric Company, 2 months. Northwestern Terra Cotta Co. 2 months, 1904. C. A. Chapman, ten months, 1905. The Arnold Co., ten months, 1906, made all designs and estimates for proposed Chicago passenger subway, in report to Chicago City Council on Subways. Other engineering work: Designed and made all preliminary layouts St. Clair Power House, Fort Huron, Mich. Charge of the valuation cable track construction, and graphical charts representing franchise values, in the recent valuation of the Chicago Street Railways. Present position: Resident mechanical engineer for Stuart Beebe Co., Pittsburg, Oglesby, Ill., engaged on design and construction of 3000 K. W. turbine power plant for the Chicago Portland Cement Co.

Junior Member Western Society of Engineers.

References: M. E. Cooley, P. M. Chamberlain, F. A. Krehbiel, N. D. Fraser.

FRANK CUSHMAN, JR., Kansas City, Mo. Born: East Boston, Mass., July, 1879. Education: 2 years Mass. Inst. of Tech. Drafting room: Steam Engine Design, English Iron Works Co., Kansas City, Mo. summer of 1905. Computor and draftsman with Tuttle & Pike, Kansas City, Mo., summer of 1906. Machinist Boston Tow Boat Co., East Boston, Mass., summers of 1897–1899, 1900–1901. Marine Engine work. Other engineering work: Asst. instructor in machine tool work, Mass. Institute of Tech., 1898–1901. Instructor in forging and mechanical drawing, Manual Training High School, Kansas City, Mo., 1901–1903. Instructor in machine tool work and director of Dept., 1903, to date. Expert work for Kansas City Elevator Mfg. Co., 1906. Present position: Instructor in Mach. Tool Work and Director of Dept., Manual Training High School, Kansas City, Mo.

References: James M. Kent, Peter Schwamb, Richard J. McCarty.

GEORGE HOWARD DAVIS, Pawtucket, R. I. Born: East Providence, R. I., September, 1876. Education: M. E., Brown University, 1899. Other engineering work: Draftsman on machinery and mill construction Dunnell Print Works, Pawtucket and W. H. Dunnell Works, Apponoag, R. I., 1899 to 1900, 1901 to 1902. Draftsman and Inspector with A. B. Slater, Jr., on gas works construction and equipment, Sept., 1900 to July, 1901. Ordnance Department, U. S. Army, draftsman, April, 1902 to July, 1903. General Elec. Co., Lynn, Mass. on steam and gas turbine work, 1903–1905. Bureau of Yards and Docks, Navy Dept., Washington, D. C. designer and checker on structural steel and concrete steel

work, 1905-1906. Present position: Mechanical Engineer, John J. Kenyon Mfg. Co.

References: A. B. Slater, Edw. R. Bullock, Wm. B. Tuttle.

IRVIN C. DEHAVEN, Indianapolis, Ind. Born: Wellersburg, Pa., July, 1878. Education: B. S. M. E., Purdue Univ., 1905. Apprentice: Railroad engineering, B. & O. R. R., Cumberland, Md., 3 years during school vacation. Drafting room: A. Sorge, Jr. & Co., Chicago, 4 months. A. Sorge, Jr. & Co., Indianapolis, 14 months feed-water purification and heating. Shop experience: B. & O. R. R. shops, Cumberland, Md., Aug., 1902, June, July, Aug., 1903, and June, July, Aug., 1904. Present position: District Manager for A. Sorge, Jr. & Co., Indianapolis, Ind.

References: Theo. Weinshank, J. R. Whittemore, W. F. M. Goss.

FREDERICK HARRY DORNER, 88 17th St., Milwaukee, Wis. Born: Milwaukee, Wis., June, 1881. Education: B. S. M. E., University of Wis., 1905. Drafting room: Special tools and jigs, etc., 1900–1901, Milwaukee Harvester Co. Special Machinery, Flour Mill Dept., Allis-Chalmers Co., June-Sept., 1902. Shop experience: Repair work Krueger Mfg. Co., Milwaukee, Wis., June-Nov., 1900. Erecting floor Allis-Chalmers Co., setting valve gear on corliss engines, June-Sept., 1903. Other engineering work: Engine Dept., Allis-Chalmers Co., June-Sept., 1904. Steam Turbine Dept., 1905–1906, Allis-Chalmers Co., on Parson Steam Turbine. Asst. in charge steam turbine experimental work Allis-Chalmers Co., Nov., 1906 to present time. Present position: Engineer with Allis-Chalmers Co.

References: Oliver B. Zimmerman, C. G. Sprado, J. F. Max Patitz.

EDWARD HALL FAILE, New York. Born: New York, N. Y., January, 1884. Education: M. E. Cornell University, June, 1906. Shop experience: July and August, 1902 in machine shop of American Hoist & Derrick Co., St. Paul at general machine work. July and August, 1904, in locomotive shop of D. & H. R. R., Troy, N. Y. at general repair work and valve setting. Other engineering work: Since finishing college in April, 1906: Held position as assistant to John S. Griggs, a consulting engineer. Present position: Assistant to Consulting Engineer.

References: R. C. Carpenter, D. S. Kimball, A. W. Smith.

RICHARD WALTER FROHWEIN, New York. Born: Brooklyn, N. Y., February, 1884. Education: 3 years Cooper Institute Engineering and Scientific Course. Apprentice: Frederich Emerich, Engineer and Machinist, 1901, candy machinery, special tools, engine and boiler repairs. Drafting room: Water meters and tools for turning out same, Neptune Meter Co., Long Island, 1902-1903. M. H. Treadwell Company, cars, cranes, hoists and special machinery. Shop experience: Inspector of cars and special machinery at Braddock Machine & Foundry Co., Braddock, Pa. Christiana Machine Co., Christiana, Pa., Ætna Foundry and Machine Co., Warren, Ohio and M. H. Treadwell & Co., Lebanon, Pa., 1906. Other engineering work: Designed industrial railway equipment at John T. Lewis Co., Philadelphia, Pa. Experimental tests on water meters, Neptune Meter Co. Assistant Engineer for M. H. Treadwell Company, in designing and supervising construction of Blast Furnace, Cars, Sugar Machin-

ery, Grate and Furnace Specialties and General Machinery. Present position: Purchasing Agent, M. H. Treadwell Co.

References: Alfred H. Stevens, Thomas H. Briggs, W. Elliston Farrell, William C. Coffin.

FLOID MERRILL FULLER, Boston, Mass. Born: Scranton, Pa , September, 1883. Education: S. B. Mass. Inst. of Tech., 1906. Present position: Asst. Instructor mechanical engineering laboratory, Mass. Inst. of Technology.

References: G. Lanza, E. F Miller, Peter Schwamb.

JOHN ANTHONY GARRETT, Los Angeles, Cal. Born: Portland, Mo., November, 1877. Education: B. S. University of Michigan, 1904. Apprentice: Fairbanks, Morse & Co., 1904–1905. Drafting room: Stewart Hartshorn & Co., Muskegon, Mich., head of drafting department. Other engineering work: Superintendent installation of Fairbanks, Morse & Co. exhibit at Lewis & Clark Exposition, Portland, Ore., 1905. Superintended installation of large sizes of multiple cylinder units (80 to 150 H. P.); 1905 to present, also carrying on extensive tests on crude oil generators in connection with larger multiple cylinder units. Present position: Gas and mechanical engineer, Fairbanks, Morse & Co., Los Angeles, Cal.

References: M. E. Cooley, J. R. Allen, W. L. Miggett.

GEORGE ERNEST HACKETT, Roselle, N. J. Born: Minnesota, January, 1880. Education: B. S., M. E., Purdue University, 1901. Apprentice: Winona, Minn., C. N. W. R. R., 1895–1899 machine and branch work. Illinois Central shops, Chicago, and Link Belt Machine Co., Chicago, three summers during college vacations. Shop experience: Soo Line Minneapolis, March to November, 1899. Great Northern, St. Paul, Minn. and West Superior Wisconsin, November, 1899–April, 1900. National Iron Works (Duluth, Minn.), April, 1900–September, 1901. Other engineering work: 1905–1906 general piece work inspector C. R. R. of N. J. Present position: General Foreman Machine shop, Elizabethport, N. J., C. R. R. of N. J., January, 1906, to date.

References: M. J. Golden, Wm. McIntosh, W. F. M. Goss, B. P. Flory.

CLIFFORD F. HUTCHINGS, Montclair, N. J. Born: New York City, N. Y. October, 1881. Education: M. E. Stevens Institute of Technology, 1902. Drafting room: Edwin H. Ludeman (N. Y. City), 1902–1903. Other engineering work: Texas & Pacific Coal Co. (Tuhber, Texas), Asst to Mine Engineer, July, 1903, to Feb., 1904. General Electric Co. (West Lynn, Mass). Steam turbine testing department, March, 1904, to June, 1905. Sprague Elec. Co. (Blowerfield, N. J.) June, 1905, to date. Present position: Assistant to Engineer, Hoist Department, Sprague Electric Co., Blowerfield, N. J.

References: Sam'l H. Libby, Paul Muller, J. E. Denton.

RASMUS MARTIN HVID, Minneapolis, Minn. Born: Strands, Denmark, February, 1882. Education: 2 years Aarhus Technical College, Denmark. Royal Danish Naval Engineering College, Copenhagen, January, 1902. Apprentice: S. Frichs, Aarhus, Denmark, 1896–1899, Erecting floor. Drafting room: Engine draftsman Allis-Chalmers Co., Milwaukee, Wis., July, 1906, to date, Minneapolis Steel & Machinery Co., Minneapolis, Minn. Shop experience; Erecting

machinist, 1903–1905, Allis-Chalmers Co. Present position: Mechanical Draftsman and designer Minneapolis Steel & Machinery Co.

References: Joseph Garbett, M. Levin, Henry C. Ord.

ROBERT F. JACOBUS, Ridgefield, N. J. Born: Ridgefield, N. J., Feb., 1881. Education: M. E. Stevens Inst., 1904. Present position: Asst. to Chemist at Waterside station of the New York Edison Co.

References: Alex. C. Humphreys, Geo. Dinkel, Adam Reisenberger, D. S. Jacobus.

ALEXANDER LEWIS JENKINS, Cincinnati, Ohio. Born: Near Eminence, Kentucky, January, 1881. Education: Kentucky State College, B. M. E., 1904. Drafting room: The Hydraulic Press Mfg. Co. (Mt. Gilead, Ohio), Chief Draftsman and Designer, June to Sept., 1906. Other engineering work: Pikesville Electric Light Plant (Kentucky), installation and operation, 1904. Engineer and electrician for the city of Jackson, Tenn., in charge of electric light and pumping station, assisted in installation and operation of six million gallon pumping engine and its auxiliaries, 1905. Design sixty ton cider press with conveyor, etc. complete, five hundred ton olive press complete, eight hundred ton Kornit press with steam heated dies and removable chase. Present position: Instructor Mechanical Engineering, University of Cincinnati, Cinn., Ohio.

References: John T. Faig, J. B. Stanwood, W. H. Collier.

LEO J. MATTY, New York, N. Y. Born: Denver, Colo., December, 1878. Education: M. E. Columbia University, 1903. LL.B. New York Law School, 1905. Present position: Patent Lawyer.

References: Casin W. Obert, W. G. Laird, Charles E. Lucke.

NEAL TRIMBLE McKEE, Cleveland, Ohio. Born: Mt. Sterling, Kentucky, January, 1882. Education: State College of Kentucky, B. M. E., 1903. M. E., 1906. Special Apprentice: Lake Shore & Michigan Ry. Co. 1903–1906, working on all sub-departments of the Locomotive and Car department, including locomotive and car repair work. Drafting room: Office Mechanical Engineer during apprenticeship, three months. Other engineering work: Engaged in making special tests and in devising methods for improving, cheapening and increasing the output of the locomotive and car repair shops of the L. S. & M. S. Ry. Co. Present position: Asst. Shop Mechanical Engineer, Lake Shore and Michigan Ry. Co., Collinwood, Ohio.

References: H. H. Vaughan, H. E. Smith, G. M. Basford, W. L. Bronaugh.

ROBERT GEORGE MERZ, Newark, N. J. Born: Newark, N. J., November, 1882. Education: B. S. N. Y. University, 1904., M. E. N. Y. University, 1905. Drafting room: Lambert Hoisting Eng. Co., Newark, N. J. June-Sept., 1902, general drafting on hoisting machinery, cableways, pile drivers, etc. American Process Co., N. Y. City, 1904–1905. Shop experience: Superintendent construction of experimental cotton picking machine, at shops of Chapin-Love Mach. Co., New Orange, N. J., for Mr. A. A. Hammerschlag, Director of the Carnegie Schools at Pittsburg, Pa. Other engineering work: 1905 to date in charge of drafting department and office engineer American Process Co., N. Y. City.

Designed sand drying plants for Brooklyn Heights R. R. Co., N. Y. and greenville Silica Sand and Quarry Co., Greenville, Pa., installed machinery at latter plant. Present position: Asst. Mechanical Engineer and Chief Draftsman American Process Co., design inspection installation of automatic pressing, drying and cooking machinery, also elevating, conveying and power transmitting machinery.

References: Gustave R. Tuska, W. Collins, P. Bliss, Chas. E. Houghton.

OTTO NICHOLAS MUELLER, 620 North East St., Indianapolis, Ind. Born: Indianapolis, Ind., April, 1883. Education: B. S. M. E. Purdue University, 1904. Other engineering work: During last three years designed the steel frames for a large number of mill buildings, office buildings, churches, etc. Assisted in working up the mechanical equipment of the Noelke Richards Iron Works. Obtained patent on a new concrete reinforcing bar.

References: W. F. M. Goss, Jas. D. Hoffman, L. N. Ludy.

VICTOR H. MUELLER, Indianapolis, Ind. Born: Newark, N. J., January, 1881. Education: M. E. Stevens Institute of Technology, 1906. Apprentice: Gould & Eberhardt, Newark, N. J., 1896–1902. Drafting room: Gould & Eberhardt, Newark, N. J., 1900–1902, machine tools. The Ball & Wood Co., Elizabeth, N. J., Jan.-Oct., 1902. Crocker-Wheeler Co., Ampere, N. J., June-Oct. 1903. Crocker-Wheeler Co., June–Oct., 1905. Shop experience: Gould & Eberhardt, Newark, N. J., 1896–1900. Other engineering work: Chief Draftsman, The M. W. Kellogg Co., Jersey City, N. J. Present position: Chief Draftsman, N. Richard I. Works.

References: Albert W. Jacobi, F. L. Eberhardt, D. S. Jacobus, W. H. Bristol.

WILLARD LACY POLLAND, Waukesha, Wis. Born: Monmouth, Ill., June. 1882. Education: B. S. University of Illinois, 1906. Drafting room: A. L. Ide, July-Sept., 1904, Springfield, Ill. N. Dubois, June-Sept., 1905, Springfield, Ill. Western Elec. Co., Chicago, June-July 1906. Modern Steel Structural Co., Waukesha, Wis., July-April, 1907. Shop experience: Avery Mfg. Co., June-Sept., 1903, Peoria, Ill. Macalenan Boiler Shop, May-July, 1904, Peoria, Ill. Present position: Draftsman Modern Steel Structural Co., Waukesha, Wis.

References: C. F. Blake, L. P. Breckenridge, O. A. Leutwiller.

ROBERT WESTALL PRYOR, Jr., New York City. Born: Newark, N. J. July, 1881. Education: M. E. Stevens Institute of Tech., 1902. Other engineering work: Designing, Heating and Ventilating Plants of North Jersey St. Railway Car Barns, Botony Worsted Co., Passaic, N. J. Drying Plants of the Pacific Coast Borax Co., Horrocks Desk Co. and many others. Present position: Sales Engineer of Buffalo Forge Co. N. Y.

References: J. I. Lyle, Robert E. Hall, F. A. Phelps, F. L. Pryor.

DALE FLEMING REESE, Newark, N. J. Born: Harrisburg, Pa., May, 1883. Education: M. E. Cornell, 1905. Shop experience: Thos. Reese, Jr. Co. (Lebanon, Pa.) 1905–1906. Power House construction work; blast furnace castings, etc. Other engineering work: General construction work in Power Houses (New York) June to Oct.,1902. Barber Asphalt Co. (Perth Amboy, N. J.) in charge of the erection of 2 coal handling Towers, June to Oct., 1903. In charge erection five signal houses, Subway and other work, June to Oct., 1904. Superintendent,

plant Thom. Reese Jr. Co., entire charge departments. June, 1905, to April, 1906, Assisting in the design and development of an Automatic Smokeless Stoker under patents held by the U. S. Mining and Trading Co., April and May, 1906. Present position: Asst. Engineer, Ocean Accident & Guarantee Corporation, 350 Broadway, N. Y. City.

References: Wm. H. Wiley, Dexter S. Kimball, W. Elliston Farrell.

CARL RIGDON, Wilkinsburg, Pa. Born: Le Roy, Ill., September, 1882. Education: M. E. Ohio State University, 1905. Shop experience: Westinghouse Machine Co., E. Pittsburg, Pa., June to September, 1905, and April to July, 1906. Other engineering work: Fellow in Experimental Engineering, Ohio State University, September, 1905, to April, 1906. Present position: Erecting Engineer, Westinghouse Machine Co.

References: W. F. Magruder, E. A. Hitchcock, Horace Judd.

HENRY JACKSON SCALES, Vandergrift, Pa. Born: Altanta, Ga., March 1884. Education: B. S. in E. E. Georgia Institute of Technology, 1904; B. S. in M. E., 1905; M. E. Cornell 1906. Drafting room: Designing motors and other machinery at the Wotton Elect. and Mfg. Co., Atlanta, Ga., 1903. Shop experience: General machine work for the Wotton Elect. and Mfg. Oo., Atlanta, Ga., 1903. Present position: Since June 1906 connected with the American Sheet and Tin Plate Co., repairing and working in machine shop.

References: Albert W. Smith, W. N. Barnard, J. S. Coon, R. L. Shipman.

HARRY ADOLPH SCHWARTZ, Indianapolis, Ind. Born: Oldham Co., Ky., 1880. Education: B. S., Rose Polytechnic Institute, 1901. M. S., 1903. M. E.. 1905. Drafting room: National Malleable Iron Castings Co., Indianapolis, Ind. One year instructor in drawing, Rose Polytechnic School. Other engineering work: Miscellaneous work as assistant to superintendent of National Malleable Castings Co., Member of the American Chemical Society. Present position: Chief Chemist, engaged in experimental and research work on metallurgy of malleable cast iron.

References: Thos. Gray, Frank C. Wagner. R. C. Stevens.

J. BEAUMONT SPENCER, New York. Born: Philadelphia, Pa., May, 1886. Education: M E. Columbia, 1906. Drafting room: June, 1906, to present, estimate work and engineering with The James Reilly Repair & Supply Co., New York. Other engineering work: In charge of three boiler tests July, 1906, for The James Reilly Repair and Supply Co. In charge of test on distilling apparatus and design of same at plant of the above company. Present position: Assistant Engineer James Reilly Repair and Supply Co.

References: F. R. Hutton, S. H. Bunnell, Chas. E. Lucke, Amasa Trowbridge.

J. F. TADDIKEN, Jr., New Orleans, La. Born: St. James, La., February, 1884. Education: B. E. Tulane University, 1906. Other engineering work: Summer of 1905 assistant testing engineer to Prof. W. B. Gregory of Tulane University, who had charge of the government testing of irrigation and drainage plants. On graduating and to date assistant testing engineer for the New Orleans Sewerage and Water Board. Present position: Asst. Testing Engineer.

References: W. B. Gregory, H. F. Rugan, A. Raymond.

GEORGE CARLYLE THOMAS, Bridgeport, Conn. Born: St. Johnsbury, Vermont, November, 1882. Education: S. B. Mass. Institute of Technology. Shop experience: 1 year Wheeler & Wilson Mfg. Co., Bridgeport, Conn. 4½ months Coulter McKenzie, Bridgeport, Conn. Other engineering work: 4 months experimental work with Union Metallic Co., Bridgeport, Conn. Present position: Factory Assistant Wheeler & Wilson Mfg. Co., Bridgeport, Conn.

References: Gaetano Lanza, Edward F. Miller, Frederic M. Card.

JOHN EDWARD ZIMMERMANN, Willow Grove, Penna. Born; Buenos Aires, Argentine Republic, January, 1874. Education: A.B. University of Buenos Aires. Apprentice: Machine Shops, The Great Southern Railway, Buenos Aires. The G. V. Cresson Co., Philadelphia, Pa. Drafting room: Survey work with the Pacific Railway of Argentine. The American Pulley Co., Philadelphia on general routine work. Shop experience: The Great Southern Railway of Buenos Aires; The Geo. V. Cresson Co. Other engineering work: Superintendent in the field for The American Pulley Co., Philadelphia, upon completion of the buildings made superintendent of manufacture and assistant to the managing director. Charge of and created an entire new cost system for The American Pulley Co. which is at present in use. Present position: Secretary and superintendent.

References: Ellis C. Kent, W. F. Zimmermann, Conrad Lauer, James M. Dodge.

SUPERHEAT AND FURNACE RELATIONS

By REGINALD PELHAM BOLTON, NEW YORK

Member of the Society

In the application of superheat to any steam supply, a stable temperature or extent of added heat would appear to be a primary condition, but with the present forms of arrangements for the purpose this seems to be far from achievement.

2 A control of the temperature would in many cases be an additional advantage, and the attention of designers is evidently tending toward this feature.

3 It may therefore be of advantage to bring together some of the considerations bearing on this subject with a view to a more general interest in the methods of generating superheated steam.

4 Most of our present practice appears to be based upon the adaptation of superheating apparatus to standardized forms of boilers and settings, a leading consideration being the avoidance of disturbance of their accepted designs, or alteration of the accepted relation of boiler parts.

5 It has thus become very common practice to install superheating surface in some one position in the gas passages, where a more or less convenient space exists in a standard design, without special regard for its full desirability, or for a well adapted relation of the superheating surface to the path or travel, volume, or temperature of the gases.

6 Manifestly, if existing designs of boilers and settings are to be rigidly adhered to, this must be the case, but it would seem that the eventual aim should rather take the direction of a remodeling of the designs of both boiler and setting, in favor of the superheating apparatus, and that the latter should receive a greater consideration than its present very secondary position in the combination.

7 Merely to place a superheating coil in a certain part of the gas passage of a boiler, and to connect the steam supply to it by strange and undesirable pipe connections, as is so frequently the case at pres-

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ent, is by no means to be regarded as a complete solution of the problem.

8 In such a position, not only the design of the superheater, but often its true proportion may be sacrificed to the exigencies of boiler proportions, and its accessibility, so peculiarly necessary, becomes questionable.

9 Placed thus, or in any other position where the travel of the main body of gases from the fire envelopes the heating surface, the superheater is subjected to conditions of wide variation of gas passage and temperature, largely increasing and decreasing its output in transferred heat.

10 If its proportions be based upon a given heat transfer to a given rate of steam passage through its interior, then the addition of green fuel to the fire, or other sources of heat variation there, may affect its output to a very wide degree, probably more than could be recorded by any thermometric appliance, and with consequent wide variation in cylinder effects.

11 The operation of an ordinary furnace is subject to so many variable elements in the nature of the fuel, its combustion, draft regulation, door openings, ash and clinker accumulations, and in the human elements back of all, that so sensitive an apparatus as that which is required to add heat to high-temperature steam should be protected as far as possible from these fluctuating influences.

12 Every engineer who has conducted boiler tests will agree upon the subject of gas fluctuations, in spite of the greatest care and expertness in hand-firing, and even to some degree with the use of automatic stokers.

13 The results would be comparable, though in a greater degree, to the inverse operation of condensing steam in a forced draft air system, in which the steam coil should be subjected to a draft varying considerably in volume, excessively in temperature, and being at the same time irregularly directed upon the tube surfaces.

14 It is not an answer in full to these conditions, to so construct a superheater, that an increase in the mass of material in its composition or in its walls or setting shall be provided, so as to absorb and give off heat to make up an average temperature condition.

15 Consideration in this direction should extend also to the furnace, and take the form of arrangements designed to eliminate the fluctuations of gas flow and temperature.

16 Automatic firing may do much toward such a result, but even more appears to be realizable by the provision of some form of rever-

beratory construction, in which masses of brickwork in the form of arches or walls alternately absorb and give out excess heat.

17 Several recent modifications of furnace design appear to lead in this direction, and may evidently be productive of relatively beneficial results on the steam-generating, as on the superheating surface.

18 Arrangements are capable of combination with certain types of boiler settings, in which the superheater is provided with a separate gas-flue from the fire, with a by-pass connection to some point in the main flue or passage beyond it, which by suitable dampers may be capable of a regulation of the volume of gas passing through the superheater. If provision could be practicably added for control of the gas volume by means of apparatus affected by the temperature of the gas, the output of superheat would become a defined quantity with a given steam-flow, but with the high temperatures involved, this does not seem to be realizable.

19 Fluctuations in the steam output of the boiler would moreover, still affect the degree of superheat, although this element is one that is partly controllable by existing apparatus, inasmuch as additions to the boiler output follow on additional furnace work, so that some modification or adjustment of the rate of gas flow over the superheater, could probably be intelligently made by hand.

20 These considerations become more defined as the higher temperatures of superheat are attempted, and probably as much of the disappointment experienced in this direction is due to the lack of proper heat control, as to any other feature. The work of heat-transfer becomes rather closely balanced when steam is being superheated to the high degrees frequently employed in Europe, and when gas of relatively high temperature is necessarily being utilized for the work. Such relatively high temperature may, upon a comparatively moderate disturbance of the furnace conditions such as the introduction of fresh fuel, fall temporarily to the degree where very little heat transfer to the steam will take place, and thus the steam supply of a delicately adjusted engine is suddenly reduced very largely in temperature, and its internal work, and its metallic expansion, much and undesirably modified.

21 It may not be too much to say, therefore, that for effectively securing the higher temperatures of superheat, the furnace conditions must be such as will eliminate the fluctuations of gas flow and temperature, or the heater must be placed where control of the gas volume can be secured.

22 As regards the maintenance of a given superheat at various outputs of steam, it may be said that where the relation between the

furnace heat-output, the first heating-surface of the boiler, and the superheating surface is well related, it seems reasonable to expect that variations in total steam supply would show little variation as regards the superheat, since the increase of furnace heat would be relatively absorbed by both the surfaces referred to. This would however, be modified when higher degrees of superheat are in use, in which case less of the first boiler heat-surface must be interposed between the fire and the superheater, and relatively less of an increase of heat would be absorbed thereby, subjecting the superheater to a relatively higher temperature, disproportionate to output.

23 Desirable results seem on the face, to be more readily attainable in the separately-fired type of superheater, but in this form of the appliance the separate furnace is subject to many of the same effects of fluctuation, due to fuel, draft, and handling, that a main boiler furnace would be. Moreover, the temperature at which the gases of a separate fire must pass off from the apparatus involve some loss in heat. This escaping heat might in some cases be utilized in an economizer, or as, in the recent proposal of Mr. Hosea Webster, Member of The American Society Mechanical Engineers, these gases might be connected into the boiler gas-passages at some suitable point, and be thus utilized in steam generation.

24 An ideal condition would, perhaps, be attained by a gas-fired independent superheater connected in this manner to the boiler, a refinement not, however, generally practicable, and thus for general practice it is necessary to rely upon the development herein advocated of the furnace control by such combination of grate, arch, walls, combustion-chambers, and draft, as will to the greatest extent regulate the flow of heat.

25 The problem is one in which the designer and manufacturer of every type of boiler is interested, and which they cannot be too strongly urged to take in hand.

26 The evident trend of general steam practice is toward the use of some degree of superheat, and the boiler of the future may thus be regarded as a combined apparatus, involving fuel, air, furnace, generator and superheater, supplying with the same regularity and security with which commercially dry steam is now delivered, a superheated steam of defined quality, in any quantity up to its extreme capacity.

27 Such a combination requires not only on the part of the designer but on that of the operator and user, some greater degree of attention and interest than has hitherto been bestowed upon the subject, and we may look forward to the time when the present methods

of haphazard combinations of fuel, chimneys, grates, boilers, and superheaters, often brought together without any co-relation, and even without any distinct object, will be exchanged for a policy in which the great boiler manufacturing interests will present, and the general body of steam users will appreciate defined combinations of the furnace with superheating generators, developed from the information and experience which has been accumu'ating around the subject in recent years.

AIR COOLING OF AUTOMOBILE ENGINES

By JOHN WILKINSON, SYRACUSE, N. Y.

Non-Member

The result always first met by the investigator of the air-cooled engine for automobile work has been that the motor became too hot for proper operation, and therefore the problem has been to find out how overheating manifests itself and how to overcome the fault.

2 Overheating shows itself in quite a number of ways. The cylinder may become so hot that as a result the incoming gases expand so much that there is a reduction in power owing to the smaller amount of air and gasolene taken in; the heat may be so high that the lubricating oil will fail to perform its proper functions, causing an increase of friction which still further heats the cylinder and reduces its power.

3 This has been proved by introducing such a lubricant as graphite, which is not influenced by heat, onto the cylinder walls after the power has dropped, and noting the almost instantaneous recovery of the power. The piston head may become expanded so much that it will seize. The incoming charge may become so heated by the walls and by compression that it is ignited prematurely.

4 This generally occurs at a low engine speed and is indicated by energetic knocking. Indicator cards taken by the monograph under these conditions show the pressure to have risen very much higher than normal, indicating that a true explosion may have taken place.

5 Fig. 1 represents an ordinary monograph card, and Fig. 2 shows the high initial pressure due to premature ignition from heat.

6 Again, some projection in the cylinder of metal or accumulated carbon, or more often a red hot exhaust valve, may cause a premature explosion at high speed, or even a burning of the charge on entering the cylinder. This may also produce the same effect at low speed as

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is shown on Fig. 2. It is therefore necessary to apply such remedies as may obviate as much as possible the above conditions.

7 In order to keep the temperature of the cylinder walls within working limits, it is evident that the design must be such that either less heat must be allowed to enter the walls or more must be carried off, or both of these results must be accomplished.

8 Getting less heat into the walls involves one of the fundamental principles of the economy of the gas engine, and is best accomplished

FIG. 1 NORMAL MONOGRAPH CARD UNDER FULL LOAD

FIG. 2 PREMATURE IGNITION MONOGRAPH CARD DUE TO OVERHEATING OF ENGINE

by reducing the internal surface exposed to combustion to a minimum which means principally to design the combustion chamber as nearly spherical as possible.

9 If the internal surface is less, the less the incoming charge is heated and the less heat is lost to the cylinder walls; therefore the greater the power and efficiency; the less heat it is necessary to carry off from the walls to keep them at a working temperature. This fact does not yet seem to be well recognized, and we still see engines built with a valve pocket on each side of the cylinder.

10 The internal surface exposed to heat at the time of explosion in a 4″ x 4″ motor with a semi-spherical cylinder head is about 38 square inches; in the same motor with a valve pocket on either side of the cylinder about 74 square inches and a good part of this surface has to be left rough. It is self evident that the jacket loss must be much greater in the last instance.

11 Engines with a semi-spherical head will show a gain of 25 per cent in power and efficiency over the prevalent type with a valve pocket on each side. This type of cylinder head may also be machined smooth on the inside to reduce its absorbent effect to a minimum.

THE EXHAUST GASES

12 In passing out of the cylinder these gases raise the temperature of the exhaust valve often to the point of premature ignition, and give up their heat to the metal adjacent to the valve and to the valve passages.

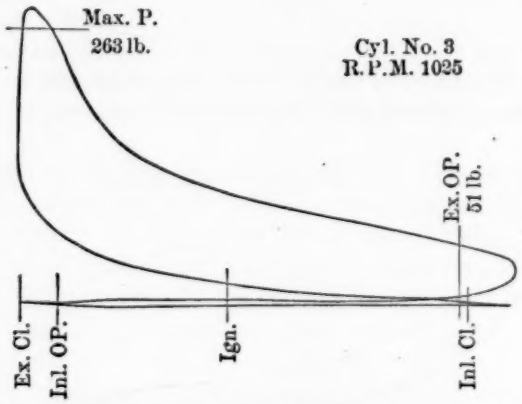

FIG. 3 MONOGRAPH CARD SHOWING EFFECT IN AUXILIARY EXHAUST OPENINGS

13 If a port is made at the bottom of the stroke, a large part of the exhaust will pass out here before the main exhaust opens, and the pressure will drop to atmosphere by the end of the stroke. Therefore the temperature of the gases passing out at the exhaust valve will be greatly reduced.

14 The exhaust passages contiguous to the cylinder should also be made as short as possible.

15 Fig. 1 shows a monograph card taken from a 4″ x 4¼″ engine with an exhaust opening 40 degrees before the end of the stroke. Fig. 3 shows a card of a 4″ x 4″ engine, with auxiliary exhaust opening at the same point.

The best internal conditions may be summed up as follows:

a To present the minimum internal surface to the heat.

b To make this surface as smooth as possible.

c To carry off the hot exhaust gases at the bottom of the stroke before the main exhaust valve opens.

d To get rid of what is left with as little surface contact with the cylinder as possible.

e To reduce the friction of piston on the cylinder to a minimum.

f To keep all projections out of the cylinder.

g To make the compression just right to fit all other conditions.

16 The above represents the *science* of air-cooling in regard to the internal conditions of the cylinder as far as the writer understands it.

17 There still remain the external conditions which, outside of the fact that the more circulation of air the better, have not yielded results that can so confidently be asserted as correct.

18 What the form, position, and material of the outside surface shall be has not been reduced to a positive science.

19 If we try to make the cooling surface part of the cylinder casting, we meet great difficulties in the way of unsound casting, insufficient area, and too much weight. If we attach pieces of copper or other good conduction metal in the form of rings or studs, it is very necessary to take great care to make an extremely good mechanical joint. No one has yet succeeded in brazing or soldering such material to the cylinder in satisfactory form. An ideal cooling medium would be a finely and equally spaced growth of copper hair metallically joined to the cylinder.

20 A still further complication of cooling is presented by the necessity of using a four-cylinder motor placed longitudinally in the car.

21 If it is attempted to cool this design by the general circulation of a fan in front, each cylinder tends to keep the air away from the next and to radiate its heat to its neighbor, and the cooling medium gets warmer as it gets toward the rear, decreasing its cooling power. It is therefore necessary to increase the cooling surface toward the rear of the engine; cylinder No. 3 requiring the most attention, and No. 2 requiring somewhat less, and No. 1 requiring very little surface, showing the efficiency of a rapid circulation on an unobstructed cylinder.

22 If we use a blower and drive the air separately over each cylinder, a large amount of power is absorbed by the blower, and a piping system of considerable complication is needed. It also has one

of the weaknesses of the water-cooled motor, namely, the danger of ruining the motor by the breakdown of the circulating mechanism.

23 In regard to the size of the air-cooled motor that could be used in an automobile, an investigation of the relative sizes of the internal surfaces, volumes, and speeds of two similar engines seems to show that the larger the engine the lower the temperature of the cylinder walls. The only parts of a large engine that get hotter than a small one are the exhaust valve and center of piston.

24 If an auxiliary exhaust port is used, the exhaust valve gets no hotter than in a smaller engine, and therefore the limiting feature of air-cooling a large engine is the temperature of the piston center. I have used 4-cylinder engines as large as 5″ x 5″ with as much success as smaller ones.

25 In view of the above, it might be asked what can actually be said of the performance of air-cooled motors in practice. A 4-cylinder 4″ x 4″ motor with a clearance space of 26 per cent of total volume delivering at the brake:

21 horse power at 1000 revolutions and
27 horse power at 1500 revolutions

or 1 horse power for each 7.4 cubic inches of displacement at 1000 feet per minimum piston speed will positively meet every condition of road use, and we hope to see in the near future 30 horse power at 1000 feet piston speed or 1 horse power for each 6¾″ piston displacement. This, so far as the writer knows, is as good as is commercially produced in a water-cooled engine of the same size.

26 As to the heat efficiency of a motor of this size, tests show it to be as high as 20 per cent, which represents 0.7 pounds of gasolene per brake horse power hour.

27 In so much as the air-cooled motor we are talking about is meant to use only on a road vehicle, it must stand or fall on its merits as such. It would not be reasonable to assert that an engine can be kept as cool with air as with water and it is not desirable to do so any way, as the efficiency will be higher with the hot motor.

28 The air-cooled motor is correct in theory in that it directly cools by the air, and the ordinary type is simpler, lighter, cheaper and proof against extreme cold and extreme heat. In respect to its cooling it is not dependent for its safety on any working mechanism. Even with the loss of its fan it can generally be brought to its destination on schedule time. Such faults as it has had have been slowly eliminated. Whether it has any inherent defects which can never be corrected is very doubtful, and its entrance into even the high powered field is only a question of time

MATERIAL FOR AUTOMOBILES

By ELWOOD HAYNES, KOKOMO, IND.
Non-Member

Since the first attempt to build automobiles, early in the 90's, experimenters have had difficulty in getting materials suitable for the purpose. Steel of high tensile strength was employed but the results were ever the same. Lower carbon steels were tried, but they lasted only a few weeks or months and then broke short off. Swedish iron did not break, but when the first hard bump was encountered it took a set and the wabbling rear wheels indicated what had happened. Finally a steel of moderately low carbon was introduced which gave only fair results, and if the car was driven for any length of time over rough roads, this also crystallized and broke off.

NICKEL STEEL

2 In 1899 a nickel steel axle was introduced into a machine by Messrs. Haynes & Apperson, and the car made successfully a trip from Kokomo, Ind., to New York, a distance of about 1000 miles, without serious breakage of any kind. This axle was made by the Bethlehem Steel Co., of Bethlehem, Pa., and so far as is now known, was the first material of this kind ever introduced into an automobile. Nickel steel was used in the axles of cars of this construction for about five years, and not a single case of breakage occurred during that period. Not only was this steel found to be practically free from crystallization, but it possessed a very high elastic limit—about 70,000 or 80,000 pounds—and a tensile strength of over 100,000 pounds, with an elongation of about 15 or 20 per cent.

3 Soon afterward nickel steel was introduced into the construction of driving chains and showed great superiority over those formerly made of ordinary steel. When the sliding gears were first used on the automobile for the purpose of changing the gear ratio between the motor and rear axle, trouble again asserted itself in breakage.

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In vain were gears made of the best form of tool steel; the ends of the teeth would break off when an attempt was made to throw them suddenly into engagement by means of the shifting levers. Trouble of a very serious nature resulted from this as pieces of the broken teeth would get into the other gears, thus causing them to break, and sometimes the entire train of gears would be almost ground to pieces on account of the breakage first of one gear and then of another.

NICKEL CHROME STEEL

4 Machinery steel, case hardened, was tried, and while this gave better results, it was by no means satisfactory. The injury and breakage of sliding gears were taken as a matter of course, and almost every person possessing a car equipped with these gears expected sooner or later to make a number of replacements.

5 It was finally discovered that an alloy consisting of iron, nickel, and chromium possessed most remarkable properties. Not only could the steel be hardened by heating to redness and quenching in oil, but it could be given a considerable amount of toughness at the same time by drawing the temper somewhat after the first hardening. If the steel was properly made and afterward properly treated it was found to be almost impossible to break one of the teeth in a 6-pitch gear by means of a heavy hammer. So successful were these gears that they rendered it possible to run an entire season sometimes without the breakage or serious injury of a single tooth. Front axles, steering knuckles, and other important parts requiring high elasticity were made of this steel in certain cars with very good results.

ALLOY TOOL STEEL

6 The greatest difficulty encountered by the manufacturer was in the working of the steel, which was found to be extremely difficult. Fortunately, about the time of its early introduction a tool steel was discovered which possessed most remarkable properties. This steel consists mainly of an alloy of tungsten, chromium, and iron, with but a very small per cent of carbon. One of the most remarkable properties of this steel is its capability of becoming very hard and tough when quenched from a glowing white heat by dipping into a bath of oil. This method of tempering would ruin ordinary tool steel, but it produces in the tungsten chromium steel a substance which is capable of cutting the hardest forms of nickel steel and nickel chromium steel with comparative ease. While this alloy tool steel is not used in the actual construction of the automobile, it is referred to

because its use is essential in the turning and machining of the high strength alloy steel.

7 It has been found that the manufacturing and working of nickel chrome steel requires great care, as there seems to be some tendency toward segregation when the steel is in the process of making, which gives rise to hard and soft spots in the finished metal. If an attempt is made to manufacture gears from material of this character, it will be found that some of the teeth are extremely hard while others are just about the right hardness. On the other hand, even if the steel is of uniform composition and texture throughout, it will not stand very great variation of temperature without danger of injury, since it is very sensitive to heat treatment. When properly made and properly treated, however, it is perhaps the most resistent substance yet produced so far as the resisting shocks and blows is concerned. It has been found almost impossible to break a tooth from a 6-pitch gear made from this material, even with the use of a heavy hammer. This renders it especially suitable for sliding gears which are subjected to the destructive action due to the striking of the teeth when forced into mesh while in motion.

8 The following may be taken as a test of high quality nickel chrome steel made by the Krupp Company, of Essen, Germany. It will be noted that much depends upon the treatment of the steel:

DIMENSIONS OF TEST BARS, 5.91″ LONG AND 0.59″ DIA.

	Normal	Slightly hardened	Greater deg. of hardness.
Elastic limit, lbs. per sq. in.	86,909	148,072	193,589
Tensile strength, lbs. per sq. in.	111,943	155,326	221,325
Elongation, per cent	14.5	9.1	7.7
Contraction, per cent	64.0	55.6	46.2

9 It will be noted from the above tests also that under the hardening treatment the tensile strength rises rapidly, and the same may be said of the elastic limit, rising as it does from 86,909 pounds to 148,072 pounds when slightly hardened, while the tensile strength rises from 111,943 to 155,326. With a greater degree of hardness the elastic limit reaches 193,589 and the tensile strength 221,325. It will be also noted that the elongation gradually diminishes from 14.5 per cent in the normal steel to 7.7 per cent in the more highly hardened specimen. The contraction of area also falls from 64 per cent in the normal to 46.2 per cent in the highly hardened steel. The contraction of area does not suffer so much, as the elongation. The comparatively small loss in contraction of area is a good sign, since it indicates that the texture of the steel has been well preserved under treatment.

10 Plain nickel steel containing a very small per cent of carbon is also a good safe material for automobile work. The following may be taken as an example of a mild low carbon nickel steel:

Elastic limit, 65,146; tensile strength, 81,561; elongation, 23.9 per cent; contraction of area, 71 per cent.

11 It will also be observed from this that while the elastic limit is quite low as compared with the nickel chrome steel, it is high as compared with ordinary carbon steel and that the elongation and contraction of area are very high indeed, indicating a very safe material for almost any construction. This material not only possesses these excellent properties, but resists dynamic stress remarkably well—in fact if the dynamic stresses are not too close to the elastic limit of the steel, it will preserve its strength and quality for an indefinite time. The following tests indicate the quality of this material as compared with carbon steel:

Carbon steel, 15,000 vibrations; nickel steel, 34,000,000 vibrations. —(Not broken).

12 The former shows the carbon steel under combined torsion and vibration, and the latter nickel steel under the same test. It will be observed that whereas the carbon steel withstood only 15,000 vibrations, the nickel steel was not broken under 34,000,000 vibrations.

VANADIUM STEEL

13 Besides the steels already mentioned, there is another which is now attracting considerable attention; namely, that produced by adding a small quantity of vanadium to a nickel steel or chrome steel. Since vanadium has until recently been classed among the very rare elements, it may perhaps be in place to mention a few of its properties; it is prepared from the chlorid V Cl_2, which is reduced by means of a current of hydrogen gas, the chlorid being heated while the reduction is taking place. Simple as this process may seem, it is one of the most difficult known to chemists, and it usually requires three or four days to prepare a fraction of an ounce of the metal by this process. Until quite recently this element and its compounds, owing to their rarity, were very expensive, but we are now assured by the American Vanadium Company that a sulphid of vanadium has been discovered in an immense quantity in the Andes mountains of South America, and that they are now prepared to furnish the metal in the form of a ferro alloy known as ferro-vanadium in any quantity desired.

14 This ferro vanadium contains about 20 per cent of the latter metal and is readily incorporated with the iron or steel during the

melting, either in the open-hearth or crucible process. Mr. J. Kent Smith, who has given the subject of vanadium steel much attention, advocates the open-hearth process as preferable to the crucible process for the making of this steel. This steel possesses most remarkable qualities, notwithstanding the small quantity of vanadium which it contains. One of these is the closeness with which its elastic limit approximates its tensile strength, and since the former quality is the one in which the greatest dependence is placed, this is a very desirable characteristic. The sharp contraction of area, also a characteristic of this steel which together with the silky fracture it usually presents, is also a strong indication of the splendid quality of this material. Moreover, the fracture is nearly always of this quality, even though the steel has been highly tempered.

15 The following are the results of some tests made on oil treated bars of the above steel: It is a rather remarkable fact that the vanadium alone or with carbon does not give much character to the iron or steel, but when a third element is introduced, such as nickel or chromium, the characteristics of the steel are changed for the better. Whether the vanadium acts as an essential element in the composition of the steel or principally as a purifier is not fully known; it has been found, however, that a certain amount of the vanadium introduced (about $\frac{1}{4}$ per cent), must remain in the steel in order to give it its characteristic properties. Vanadium, however, has a strong affinity for nitrogen as well as for oxygen, and it may be that it acts as a purifier of the steel by combining with minute quantities of nitrogen gas, which might otherwise be occluded in the steel and thus interfere with its compactness and strength.

16 It will readily be seen that the high elastic limit, strong contraction of area and splendid silky fracture, together with the large number of vibrations which the steel endures under dynamic stress, most strongly recommend this steel as almost ideal for many parts of the motor car. The writer has made some experiments in the forging, and found that it works well under the hammer, though it must not be allowed to become too cold or it will resist pounding to a remarkable degree. It is not readily injured under the forging hammer, provided due care be taken not to heat it too rapidly. Another valuable property of the steel is the fact that it machines more readily than nickel chrome steel—in fact, more readily than plain nickel steel.

BRONZE

17 The use of bronzes in the motor car must necessarily be restricted to parts requiring low rigidity, and usually also moderate

strength. While it must be admitted that samples of bronzes can be made that approach closely to fairly good grades of steel in tensile strength, elastic limit, and contraction of area, it must also be remembered that the modulus of rigidity of iron and steel is about 28,000,000 pounds, for example, while that of bronze is only about 15,000,000 pounds. This means that a bar of bronze of a given size and form under given conditions will deflect nearly twice as much under the same load as a similar bar of iron or steel. In most parts of the car this feature is objectionable, since changes of alignment are likely to occur, unless the parts which are made of this material are especially well designed.

18 Notwithstanding the above objection the readiness with which bronze lends itself to the production of castings of various parts, and its freedom from crystallization under dynamic stress has led to its introduction into many of the minor parts of the motorcar, such as small hand levers, carburetors, tubing, crank cases, gear cases, etc. In general, it may be said that it is suitable for the small levers such as those used for controlling the sparking mechanism, carburetor, etc. Another use for this metal is in bearings, although these require a decidedly different composition from that used for levers, crank cases, and like parts.

19 The parts requiring strength are usually made from nickel bronze, phosphor bronze, manganese bronze, or aluminum bronze, while the bearing bronzes are composed usually of lead, tin, and copper in various proportions. Under this latter head come also the so called babbit metals which vary greatly in their composition, some of them being composed of lead, copper, tin, and antimony; others of lead, tin, zinc, and antimony, and still others of lead, tin, and antimony. It is not the purpose of the writer to discuss the merits of these various bearing metals, since a number of very good ones can be readily obtained on the market.

20 Beside the above alloys, pure copper is used to a considerable extent in the construction of radiators, gasolene tanks, etc. It is well adapted for the construction of radiators, since it can easily be soldered; is one of the best conductors of heat, and is readily formed into almost any shape on account of its malleability, ductility, and comparative softness.

ALUMINUM

21 Aluminum is now used very largely in automobile construction, and it is a significant fact that it was first introduced into the automobile in America, though the French used it to some extent quite early

for a few minor parts of their machines. Pure aluminum is used only for a few special purposes, and even then to a limited extent—most notably for tubing and radiators. It is quite well adapted for the latter purposes in many respects, but the comparative difficulty experienced in soldering it is somewhat of a drawback. On the other hand, when alloyed with copper or some other metal giving it increased hardness and elasticity, it is well adapted for various purposes such as seats, gear cases, crank cases, dashes, and various other parts of the car. Its extreme lightness, together with the ease with which it may be machined and the facility with which it may be cast, renders it very useful for many parts of the machine.

22 An alloy of zinc and aluminum seems to have considerable rigidity and elasticity, as well as quite high tensile strength. It is also cheaper than the aluminum copper alloy, but experiments made by the writer indicate that this alloy is not safe if subjected to repeated vibrations, since it seems to fatigue quite rapidly and sooner or later breaks off short. For example, a ½-inch square bar made of an alloy of aluminum and zinc withstood only about 15,000 vibrations before breaking, while an alloy of copper and aluminum withstood 1,600,000 vibrations of the same amplitude and frequency without breaking or showing any signs of injury except a very slight set. Aluminum also forms a very light alloy with magnesium, which, however, is too expensive for ordinary use and is somewhat difficult to handle in quantity. A number of other alloys of aluminum have been prepared, and to some extent used in automobile construction—the most notable perhaps of which is an alloy of tungsten and aluminum, which has been used to a considerable extent abroad, but is not used in American cars so far as the writer is aware.

23 From the foregoing it may be said that the following substances have proved suitable for the various parts of the automobile:

a For rear live axles, nickel steel containing from 4 per cent to 5 per cent nickel and less than 0.3 per cent carbon.

b For front axles, steering knuckles, propeller shafts, etc., vanadium steel.

c For sliding gears, nickel chrome steel hardened throughout, or mild nickel steel case hardened.

d For crank shafts, nickel steel or vanadium steel.

e For frames, low carbon open-hearth steel, mild nickel steel or nickel chrome steel.

f For nearly all other parts of the car, such as hand levers, tubing, etc., a good open-hearth steel of comparatively low carbon—say 0.4 per cent or under—is of suitable

quality, since there is no advantage gained by using high class steels for these purposes for the reason that the rigidity of these parts is of prime importance, and in order to make them sufficiently rigid, they must be made much more than sufficiently strong; therefore, since all steels are practically equal in rigidity, one steel is, broadly speaking, as good as another for these parts.

24 The use of bronze should be restricted largely to minor parts; the reducing gear wheels, small levers, etc., can be made of phosphor bronze, while the bearings should be made of some good composition bronze—an alloy of copper, lead, tin and zinc answers well for this purpose, but the main bearings for the engine, such as the crankshaft, crank pins, etc., should be made of a special bearing metal, which is very firm and at the same time will not injure the crankshaft in case the lubrication becomes deficient. The crank case of the motor, the gear case, and other similar parts may well be made of aluminum, since it is light, strong, and easily cast into the proper shape. Steel would answer for the above parts if it could be conveniently worked into the proper form.

25 It will be noticed from the foregoing that the most progressive automobile builders have spared neither pains nor expense in obtaining the very best materials that can be produced, because in order to obtain the highest results in automobile construction, it is necessary that material of superior quality shall be used for certain parts of the machine. Perhaps there is no form of construction that taxes the ingenuity of its builders more severely than the building of a good automobile. Take for example one of the high powered touring cars carrying from five to seven persons and equipped with a motor of 50 horse power. Now consider that this motor is sometimes geared down to such an extent that its direct torque is multiplied ten or twelve fold on the rear axle; consider further that the driver of the machine is often entirely inexperienced, and to a large extent ignorant of the strength of the material and the use of power, and it will be realized that the chances for trouble when driving an automobile are certainly very great.

26 Now add to the stresses and possible abuses from the foregoing, the severe jolting and jaring of the rough roads in America and some idea may be formed of the severe ordeal through which an automobile must pass during a season's run. It has been the general experience of builders that the more ignorant the owner of the machine, the greater his complaint. On the other hand, those who are versed in mechanical matters and who know the sizes of parts generally used

for heavy stress, often marvel at the strength and endurance of the modern automobile. Factors of safety must be reduced to the minimum in nearly every part of the machine or excessive weight is sure to occur. Many high class machines weigh less than 70 pounds to the horse power, passengers included. Of course it is not expected that the motor shall be used constantly at anything near its maximum horse power— $\frac{1}{10}$ of its brake horse power is enough for almost any automobile motor when in daily use; high power is simply intended to meet emergencies, but the material throughout the machine must be strong enough to withstand any stress momentarily applied.

27 The following table gives approximately the strength of various materials used in automobile construction:

TABLE 2 STRENGTH OF AUTOMOBILE MATERIALS

	Modulus of rigidity	Elastic limit	Tensile strength
Aluminum alloys	8 to 11 million	10M to 15M	20M to 30M
Phosphor bronze	12 to 14 million	20,000	30,000
Manganese bronze	15 million	35,000	50,000
Aluminum bronze	15 million	50,000	75,000
Wrought iron	28 million	30,000	40,000
Mild open hearth steel	28 million	40,000	60,000
Tool steel	29 million	80,000	110,000
Nickel steel	28 million	80,000	110,000
Nickel chrome steel	30 million	160,000	180,000
Vanadium steel treated	30 million	220,000	228,000

All of the above materials stand well under dynamic stress with the exception of the tool steel, which should not be used for this purpose.

SUPERHEATED STEAM ON LOCOMOTIVES

The Use of Superheated Steam on Locomotives in the United States and Canada

By H. H. VAUGHAN, MONTREAL, CANADA
Member of the Society

APPLICATIONS

Apart from an experimental application of a smoke-box superheater on the Chicago, Burlington & Quincy Railway, between 1870 and 1874, the first application of superheated steam in North America was made by Mr. Roger Atkinson, then mechanical superintendent of of the Canadian Pacific Railway, who applied a "Schmidt" smoke-box superheater to a 4-6-0 simple freight engine in 1901. In 1903 Mr. E. A. Williams, then mechanical superintendent of the same road, applied a "Schmidt" smoke-tube superheater to two 4-6-0 compound freight engines, and the results obtained from these installations were exceedingly satisfactory, the first engine showing a saving of 25 per cent over corresponding simple engines and 18 per cent over corresponding compound engines of the same class, while the latter engines showed a saving of from 15 per cent to 20 per cent over similar compound engines using saturated steam.

2 In 1904 the New York Central & Hudson River Railway applied a "Cole-Field" smoke tube superheater to a 4-4-2 passenger engine, and in the latter part of the same year the Canadian Pacific Railway purchased 41 engines, 21 of which were equipped with this type of superheater, and 20 with the "Schmidt" smoke-tube superheater. Since that date all engines, other than those in switching service, constructed on the Canadian Pacific Railway have been equipped with smoke-tube superheaters of various types, and on December 31, 1906, there were in service on this road 197 engines equipped with superheaters of the following types.[1]

[1]For full details see Proceedings Railway Master Mechanics Association, 1905.

To be presented at the Indianapolis Meeting (May, 1907) of The American Society of Mechanical Engineers, and to form part of Volume 28 of The Transactions.

TYPE	NUMBER
Schmidt smoke-box	1
Schmidt smoke-tube	32
Cole-Field tube	21
Cole return bend	55
Vaughan-Horsey return bend	88

3 At the present time this road has on order 175 locomotives for delivery during the present year all of which are to be equipped with the "Vaughan-Horsey" type of superheater, which will make a total of 372 engines to which this principle has been applied.

4 On the railways in the United States the progress has been far less rapid, and a reasonably complete list of the engines equipped at the end of 1906 is as follows:

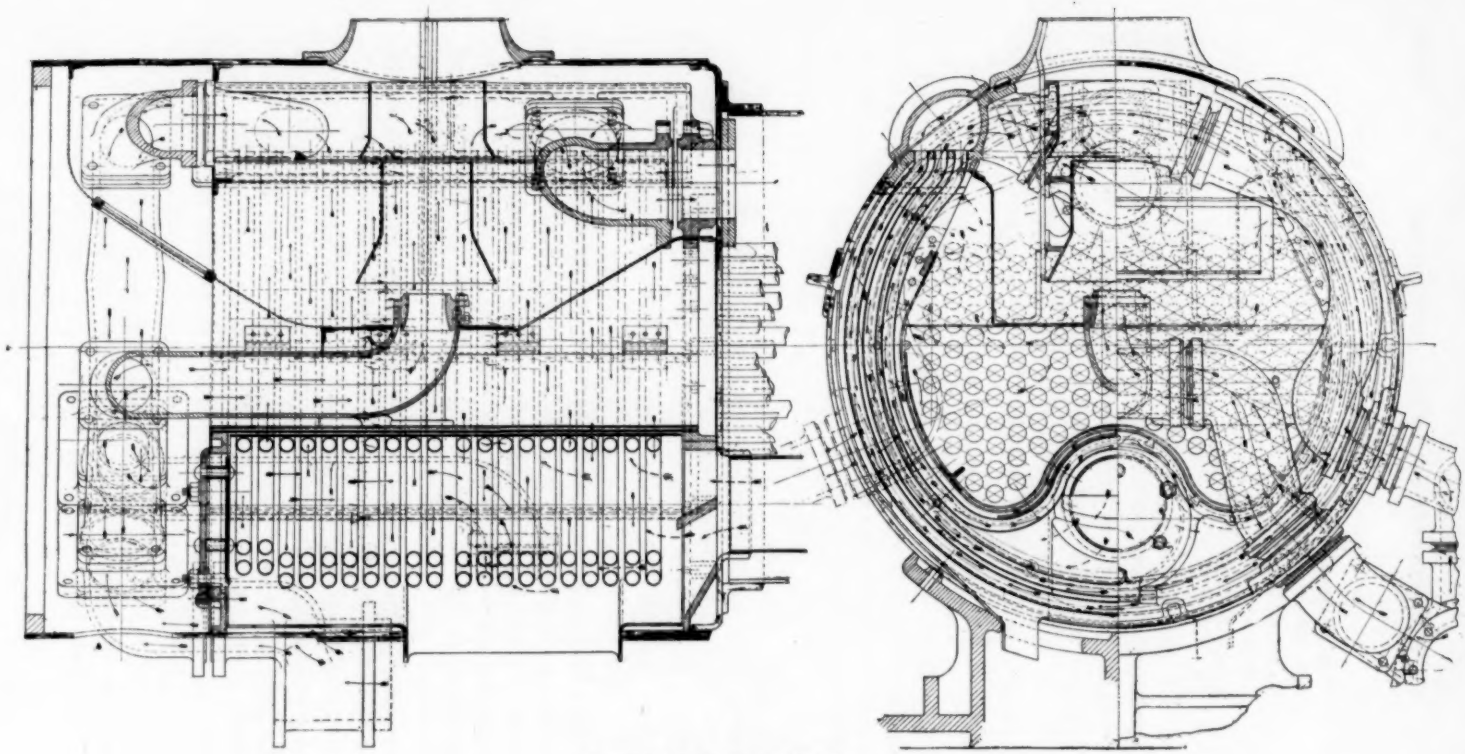
Railway	Cole	Schmidt	Vaughan-Horsey	Total
N. Y. C. & H. R.	1			1
C. B. & Q. Ry	1	2		3
Rock Island	6			6
M. St. P. & S. S. M.	1			1
C. & N. W. Ry.	1			1
Boston & Maine	1			1
L. S. & M. S.	1		1	2
Totals	12	2	1	15

TYPES

5 With the exception of one engine, viz., the first to which a superheater was applied on the Canadian Pacific Railway, all the engines enumerated above have been equipped with superheaters of the type known as the smoke-tube, this particular engine being equipped with a superheater of the smoke-box type, shown in plan and elevation Fig. 1.

6 In this design the superheating pipes are placed in the smoke-box of the locomotives, but as the temperature of the gases in the smoke-box after passing through the evaporating tubes is insufficient to superheat the steam to the requisite degree without an impracticably large amount of heating surface, a tube of large diameter leads from the firebox to the front tube sheet, by which a considerable portion of the flue gases are delivered into an annular chamber in the front end at a high temperature. The superheater tubes are located in this chamber and are thus exposed to gases of a relatively high temperature, so that the superheating surface is exceedingly efficient.

7 The steam from the boiler passes from the dome through the



Course of Steam Shown by ⇛——→
Course of Gases Shown by ⇛ – – →

FIG. 1 SMOKE BOX SUPERHEATER, SCHMIDT'S PATENT

dry pipe, into the rear end of a header placed on the right side of the smoke-box near the top, which is separated into two compartments by a transverse partition about midway of its length. From the rear compartment the steam passes through the superheater pipes to the back end of a similarly located header on the opposite side which is of the same length as the first header, but not divided into compartments. From this header the steam passes through a second set of superheater pipes to the front end of first header, and thence through the steam pipes to the steam chest. The annular space previously referred to is partitioned off from the remainder of the smoke-box and an opening is provided through which the gases, after passing around the superheater pipes, are drawn into the body of the smoke-box and thence through the stack by the action of the exhaust. This opening is provided with a damper which automatically opens when steam is admitted to the superheater and closes when it is shut off, so that the superheating pipes are only exposed to the flow of heated gases when the steam is flowing through, as the temperature of the gases passing through the large flue is sufficient to injuriously overheat them if no flow of steam is taking place through the superheater.

8 While the results obtained have been satisfactory, there are necessarily a number of joints in the front end and considerable complication of detail which in the opinion of the writer will make it very doubtful whether this type of superheater will be extensively applied in American practice.

9 The smoke-tube type of superheater which has been the one generally applied, varies almost entirely in the arrangement of the headers in the front end. The various types of Schmidt, Fig. 2 and Fig. 3, the Cole-Field tube, Fig. 4; the Cole return-bend, Fig. 5; and Vaughan-Horsey, Fig. 6, while varying slightly in the arrangement of the superheater pipes in the smoke tube, they differ largely in the form of the headers and the method by which the superheater pipes are attached to them.

10 The Cole-Field tube design is not of much practical interest as it has been but little used, and on the Canadian Pacific Railway it has been taken out of engines which were equipped with it as it was found impossible to prevent the smoke-tubes from stopping up. The same results have been obtained on other roads from which it would appear that the return-bend type is the only one giving satisfactory practical results.

11 The return bend type may be so arranged that the ends of each pair of superheater pipes enter the saturated and superheated steam headers respectively, as is shown in Fig. 3, or the ends of each alter-

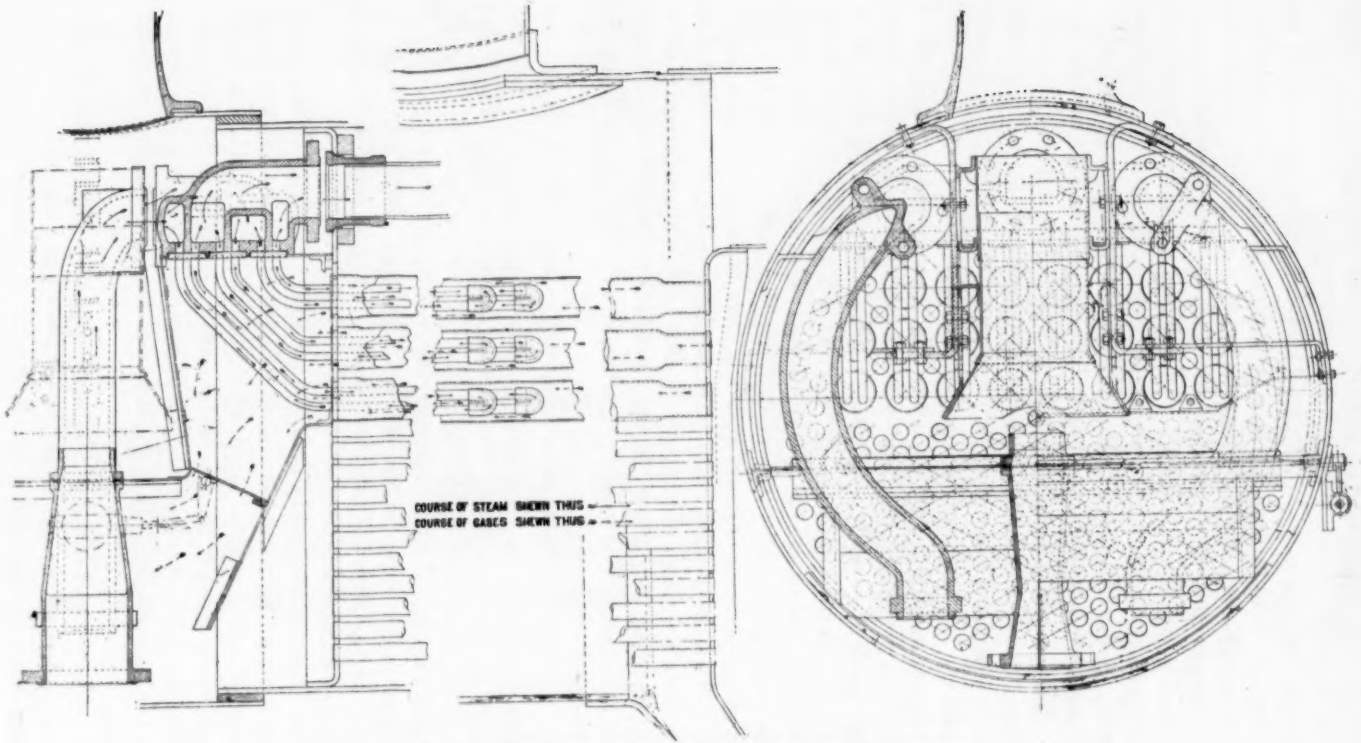
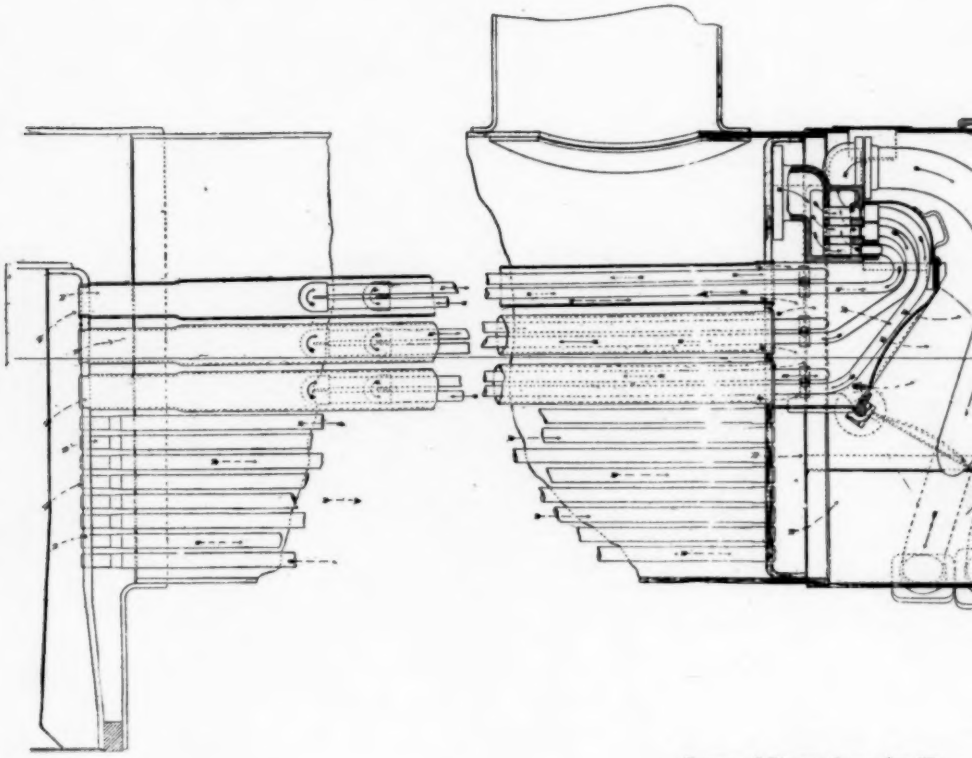
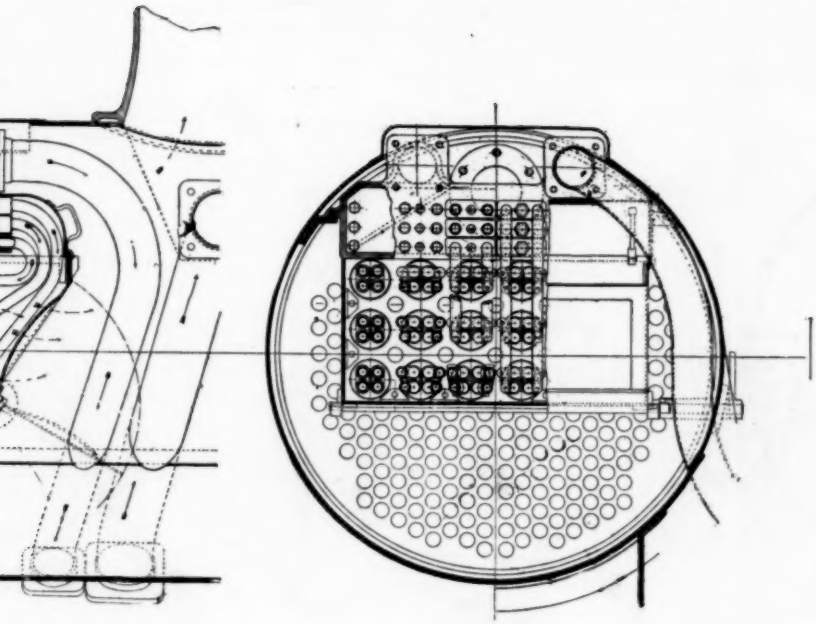


FIG. 2 SMOKE TUBE SUPERHEATER, SCHMIDT'S PATENT



Course of Steam shown by ⇛——
Course of Gases shown by ⇛ —

FIG. 3 FIRE TUBE SUPERHEATER, SCH



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ATER, SCHMIDT'S PATENT

nate pair may be joined together, thus forming a double loop in each smoke tube. It will therefore be seen that the actual variation of the Cole and Vaughan-Horsey design from the Schmidt consists in the arrangements of the headers. In the Schmidt design each group of superheater pipes is united into one flange, which is detachable from the header. In the Cole design each vertical row of superheater pipes is connected into a sub-header, the sub-headers being detachable from the main header. In the Vaughan-Horsey type each pair of superheater pipes is detachable from fittings screwed into the main headers which in this case are entirely separate and placed one above the other.

12 In all these arrangements the steam from the boiler is led by a dry pipe into the saturated steam header, thence through the loops of superheater pipes located in the smoke tubes to the superheated steam

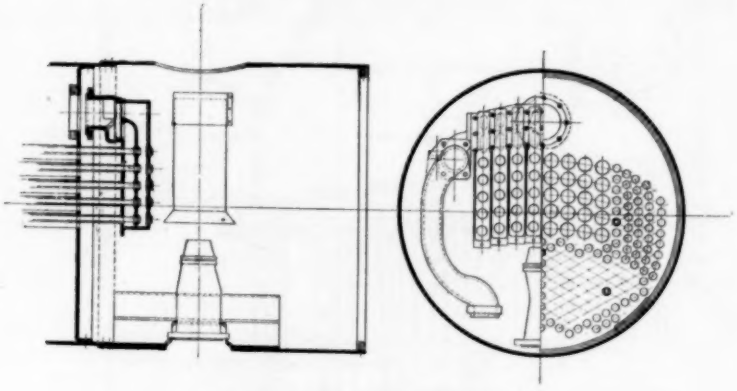

FIG. 4 THE COLE -FIELD TUBE

headers from which it is led by the steam pipes to the cylinders. The superheater headers are partitioned off from the body of the smoke-box, the partition extending to the flue sheet and provided with an opening controlled by an automatic damper, as in the previously described smoke-box superheater, by which the flow of gases from the fire-box through the smoke tubes is permitted while steam is flowing through the superheater pipes, but prevented when the throttle is shut, and the flow of steam stopped. A detailed description of these various types is given in the Proceedings of the Master Mechanics Association, 1905, and New York Railway Club, April 20, 1906.

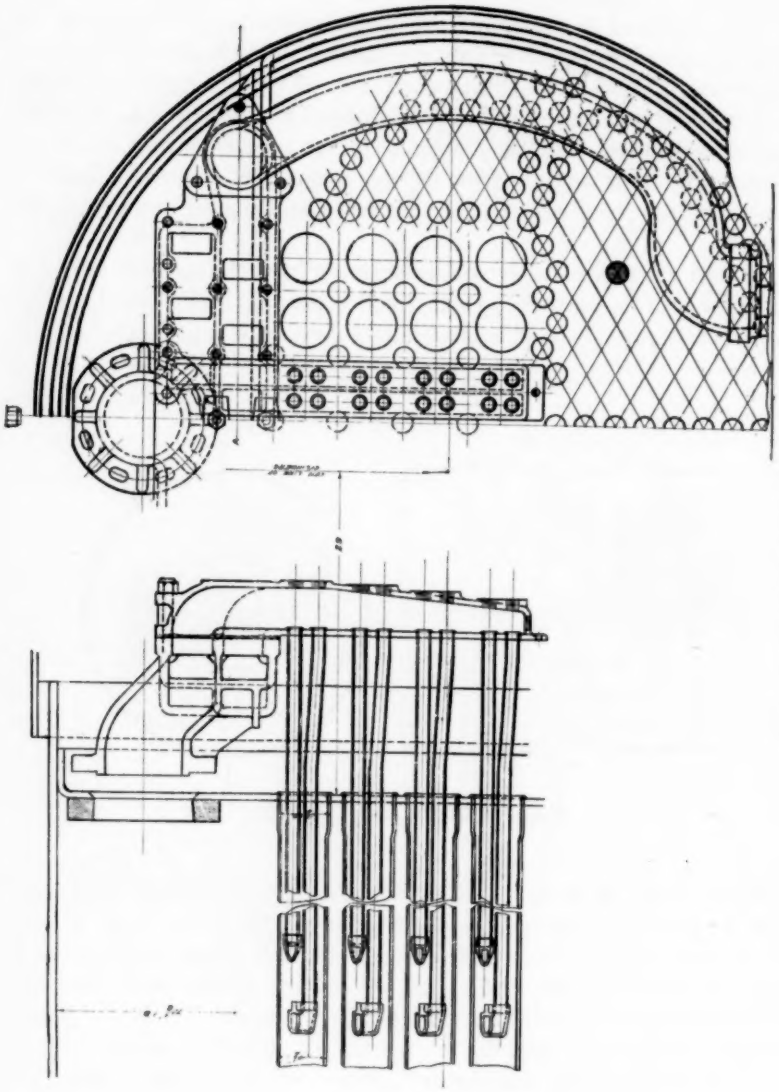

FIG. 5 THE COLE RETURN BEND TYPE

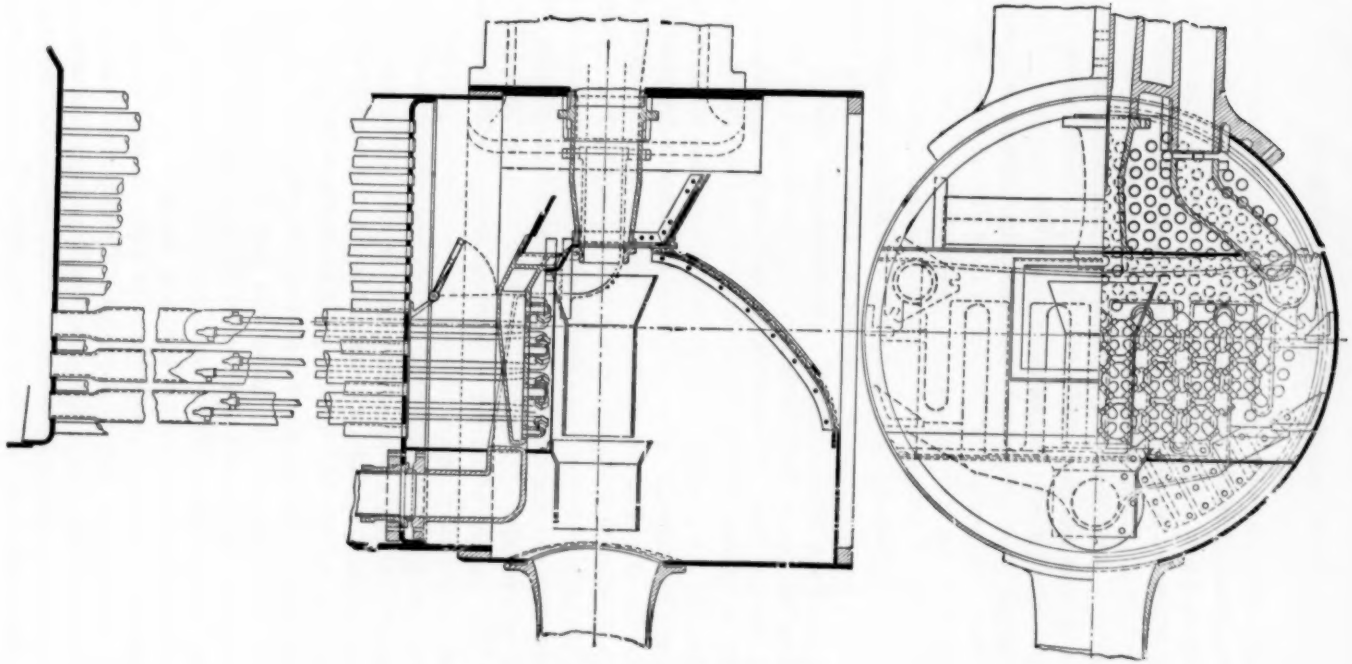

FIG. 6 THE VAUGHAN—HORSEY TYPE

13 There is one point, however, that the writer wishes to emphasize, and that is that while these different arrangements of smoke tube superheaters are given different names, the Cole and Vaughan-Horsey types are simply modifications of the Schmidt design introduced into America in 1903, and while the elements of this design were perhaps not entirely original with Mr. Schmidt, as early French patents existed showing substantially a similar construction, at the same time the credit of this modern construction is entirely his, and the other two types simply vary from it in their mechanical construction.

CONSTRUCTION

14 The large smoke tubes now made with a 5 inch outside diameter reduced to 4 inch outside diameter for a short distance from the firebox end have usually been of solid drawn steel tubing, although the Canadian Pacific Railway is now experimenting with some lap-welded charcoal iron. These tubes are threaded at the back end and screwed into the firebox tube sheet. The thread in the tube sheet is cut in position by a tap having a guide spindle fitting in a bushing in the front tube sheet in order to make this thread correspond accurately to the axis of the tube. After being screwed in, a taper maundril is driven tightly into the tube and the latter is then staved up with a caulking tool, so as to expand it as solidly as possible into the thread in the tube sheet. It is then rolled and beaded in the usual way at both ends.

15 This method of setting has proved exceedingly satisfactory. Cast iron and mild steel ferrules are used at the firebox end occasionally. They appear to offer some advantage in bad water districts, but are not necessary where the water is good. The superheater pipes are made of solid drawn steel tubing $1\frac{1}{4}$ inch outside diameter with walls $\frac{5}{32}$ inch thick. The return bends have so far been made of cast steel, but experience shows that it will be preferable to construct them of drop forgings in the future and they should be of sufficient length to cover the threads on the ends of the superheater pipes over which they are screwed. The connection of the superheater tubes to the headers varies materially in the three designs. In the Schmidt the pipes are expanded into flanges, the pipes in each smoke tube leading to one flange, and in the regular Schmidt arrangement these flanges are attached to the header by two clips between each pair of flanges, each clip being secured by a stud screwed into the header, and copper gaskets are used to make the joints between the flanges and the header.

16 In the Cole design the pipes are expanded into the sub-headers and the joints between the sub-headers and main headers are made by round wire copper gaskets, each pair of headers being secured to the main header by a clip bearing on the headers and secured to the main header by a stud.

17 In the Vaughan-Horsey design, the end of each superheater pipe is up-set, forming a flanged connection and bent at right angles to form a joint with the fittings attached to the different headers. A forged steel union nut engages the flange on the superheater pipe, and screws on to the threaded portion of the fittings, the joints being made by a small copper gasket. In the Schmidt and Cole designs the headers have usually been made of cast steel, but in the Vaughan-Horsey type a high grade dry sand casting has been found satisfactory.

ECONOMICAL RESULTS

18 The results obtained in coal economy have on the whole been exceedingly satisfactory. The results obtained from the first three engines on the Canadian Pacific Railway have already been referred to. Subsequent results on a large number of superheaters have not however shown as large a percentage of saving as would naturally be expected, when a device of this nature is applied in sufficient quantities to insure the engines with which it is equipped being treated in exactly the same way as other engines to which no particular attention is given and taking their chance with reference to the ability of the engine crews which handle them.

19 Unfortunately it is difficult to compare superheater simples with ordinary simples on the Canadian Pacific Railway, as previous to the introduction of the superheater most of the recent power purchased was of the compound type, and care has also to be exercised in making comparisons on account of the large variation in the coal consumed per ton mile on the Canadian Pacific in the summer and winter.

20 The most satisfactory comparison is arrived at by taking engines working over similar sections during the summer months, and the following table shows the performance of 2-8-0 superheater simples as compared with similar 2-8-0 compound and a 4-6-0 compound of about equal weight and also similar in design. The superheaters are of two types. M-4a being a Schmidt smoke tube return bend and M-4b a Cole-Field tube, M-3 are 2-8-0 compounds and D-9 a 4-6-0 compound. These results are those obtained during the summer of 1905.

TABLE 1

Section	Class of Engine	Total coal consumed	Coal consumed per unit mile	Relative consumption
Chalk River-North Bay.....	Cole M—4b	3048¾	128	97
	Schmidt M—4a	964½	112	85
	Comp'd D—9	175	114	86
	Comp'd M—3	1121¾	132	100
North Bay, Cartier, Webbewood.....	M-4 b	1473¾	127	100
		588¾	106	87
		510¾	113	92
		1758	122	104
Schreiber-Fort William.....		134½	145	122
		34¾	96	81
		743¾	141	118
		3876	119	100
White River, Schreiber.....		274¾	159	119
		89	134	101
		775½	150	113
		4788½	133	100
Chapleau-White River		265	140	96
		4126¾	121	83
		845½	142	97
		515	146	100
Chartier-Chapleau.....		245½	126	82
		3684¾	117	76
		565½	148	96
		728½	154	100

21 The D-9 engines may also be advantageously compared against three classes of 4-6-0 simple superheater engines of the D-10a class equipped with Schmidt smoke-tube return bend, the D-10b with a Cole return bend and the D-10c with a Vaughan-Horsey return bend.

22 These engines were run against each other during the months of September, October, November, December and January, inclusive, on the Canadian Pacific between Fort William and Winnipeg, and the general result is given in Table 2, with reference to which it should be noted that this section of the line is an exceedingly favorable one for compound locomotives.

23 Previous to the introduction of the superheater, the D-9 engines had been by far the most economical yet used on that section. The superior economy of the D-10c engines is not easy to explain, and although the writer has discussed this question at some length before the New York Railway Club, he does not feel that there is sufficient data on the subject to regard it as a definite fact.

TABLE 2

Section	1300, D—9 Comp.		700, D—10a Schmidt-Sup.		710, D—10b Cole Sup.		740, D—10c V. H. Sup.	
	Coal used	Relative consumption	Coal used	Relative consumption	Coal used	Relative consumption	Coal used	Relative consumption
Fort William to Ignace	13,144	100	207	101.0	2,993	88.5	5842	84.7
Ignace to Kenora	2,520	100	6073	98.3	14,082	105.0		
Kenora to Winnipeg	8,416	100	2170	100.8	10,443	100.5		
Total	24,080	100	8,450	100.7	28,418	99.5	5,842	85.5

24 In the early part of 1906, the Cole superheaters were removed from the M-4 engines, and therefore during 1906 were used as simple engines, thus offering a good basis for comparison with the M-4a engines. This year some other classes of engines have been introduced. Two 4-6-0 simple passenger engines Class E-5 have been converted to Vaughan-Horsey superheaters, class E-5d and some 2-8-0 simple engines class M-4e have been equipped with the same device, as well as some Pacific type 4-6-2, passenger engines class G-1-2. For purposes of comparison the results obtained from 2-8-0 class compound engines, M-1-2 of slightly smaller size than the M-4 are also shown. These engines are an economical and satisfactory type and offer a good basis for comparison.

25 Selecting sections on the Canadian Pacific on which sufficient work was done, the simple, compound, and superheater engines of reasonably similar types, the following table is presented.

TABLE 3 FREIGHT SERVICE

Section	Class of engine	Coal consumed	Coal consumed per unit mile	Relative consumption
Newport—Outremont	D–10b Sup.	207¾	128	75
	D–10c	370	163	96
	M–3 Comp.	381	148	87
	M–4b Simple	5877	170	100
	M–4e Sup.	220½	108	64
Megantic—Farnham	D–10b	342¾	182	86
	D–10c	2439	176	83
	M–3	124¾	208	98
	M–4b	3025	213	100

TABLE 3—Continued.

Section	Class of engine	Coal consumed	Coal consumed per unit mile	Relative consumption
Smith's Falls—Havelock	D–9	3579	135	109
	D–10b	7410	124	100
	D–10c	3209	125	101
	M–1–2	373½	136	110
Havelock—Toronto	D–9	494	147	100
	D–10b	521	147	100
	D–10c	501	136	93
	M–1–2	4716	147	100
Chalk River—North Bay	D–10c	2909	133	100
	M–4a	321½	102	77
	M–4b	305	133	100
North Bay—Cartier	D–10b	311	138	98
	D–10c	2257	118	84
	M–3	4425	141	101
	M–4a	501	131	94
	M–4b	505	140	100
Cartier—Chapleau	D–10b	219½	121	94
	D–10c	2837	122	95
	M–3	1264	153	
	M–4a Schmidt	2287	126	98
	M–4b	502	128	100
Chapleau—White River	D–10b	716	133	92
	D–10c	2763	125	87
	M–3	1406	155	107
	M–4a	2642	130	90
	M–4b	403	144	100
White River—Schreiber	D–10b	2977	192	130
	D–10c	231	134	91
	M–3	2188	158	107
	M–4a	1536	131	89
	M–4b	1312	147	100
	M–4e	234½	125	85
Schreiber—Fort William	D–10b	2,719	120	91
	D–10c	239½	118	89
	M–3	2051	137	104
	M–4a	1176	116	88
	M–4b	777½	132	100
	M–4e	252¾	178	135
Fort William—Ignace	D–9	967¾	97	98
	D–10b	2381	99	100
	D–10c	15304	88	89
Ignace—Kenora	D–9	472½	95	100
	D–10a	741	96	101
	D–10b	15767	95	100
	D–10c	113½	99	104
	M–4e	3173	89	90

TABLE 3—Continued

Section	Class of engine		Coal consumed	Coal consumed per unit mile	Relative consumption
Kenora—Winnipeg	D–9		2380	114	114
	D–10a		904½	88	88
	D–10b		16514	100	100
	D–10c		215	91	91
Swift Current—Med. Hat	D–9		17322	165	100
	D–10a		830½	141	81
	D–10b		778½	168	102
	M–1–2		1567	194	117
Med. Hat—Calgary	D–9		1443	146	100
	D–10a		616	122	84
	M–1–2		6058	155	107
Field—Revelstoke	M–4b		1158	317	100
	M–4e		3664	281	89
PASSENGER SERVICE					
Havelock—Toronto	E–4–5	Simp.	379	360	100
	G–1–2	Sup.	1735	220	61
Swift Current—Med. Hat	D–9	Comp.	1381	341	100
	D–10a	Sup.	5073	195	57
	D–10b	Sup.	163	228	67
Chalk River—North Bay	E–4–5	Simp.	3651	215	100
	E–5d, e	Sup.	133½	159	74
	G–1–2	Sup.	716	203	95
North Bay—Cartier	E–4–5	Simp.	2091	197	100
	E–5d,e	Sup.	318	195	99
	G–1–2		2968	166	84
Cartier—Chapleau	E–4–5	Simp.	2896	186½	100
	E–5d,e	Sup.	484½	158	85

26 In the majority of cases the superheater engines showed a decided saving, and the results between the 4-6-0 and 2-8-0 vary somewhat in accordance with the relative economy of these two general types of engines. Under some conditions the 2-8-0 are more economical, while under other conditions there is very little difference.

27 A very interesting result is that obtained from Field to Revelstoke. These are engines working on very heavy grades and are fairly comparable for two classes of locomotives involved, as they were both working together, and it will be noticed that a saving of 11 per cent for the six months in favor of the superheaters was obtained. For the larger portion of this section the engines were working at

long cut-offs where the gain from superheat would be expected to be less marked.

28 An interesting difference is shown between Swift Current and Medicine Hat. In freight service the D-9 freight compound engines show up exceedingly well in comparison with superheaters, but in passenger service on the same section the superheaters are much more efficient, the compound taking about 60 per cent more coal, due to the loss in efficiency in the compound in passenger service and the relative gain in the superheater.

29 Tests on other roads so far as information has been received show in general a reasonable amount of saving. On the Chicago, Burlington & Quincy the road records show but little difference, and on this road the experience was not satisfactory, due very probably to trouble experienced with leakage at the joints in the headers.

30 On the Boston & Maine comparative tests of two 4-6-0 engines equipped with Cole return bend superheaters in passenger service showed a gain of 14.7 ton miles per pound of coal on the engine equipped with superheated steam.

31 On the Chicago & North Western Railway tests comparing identical 4-4-2 passenger engines with and without Cole superheaters showed an economy of 9 per cent in coal in favor of the superheater.

32 On the Lake Shore & Michigan Southern tests of engines equipped with Cole and Vaughan-Horsey superheaters compared to similar engines using saturated steam showed a saving of 18.8 per cent for the Cole and 22.1 per cent for the Vaughan-Horsey superheater in coal per ton mile.

33 From the general results of these figures it would appear safe to state that from 10 to 15 per cent saving is obtained in freight service and 15 to 20 per cent in passenger service on engines equipped with superheaters as compared with those using saturated steam although this economy will be to a considerable extent lost if leakage occurs at the headers.

MAINTENANCE RESULTS

34 Results obtained from superheaters on the Canadian Pacific Railway are such as to justify a continued construction of engines equipped with this device. The past three years have developed many troubles, but they have also indicated their remedy.

35 The automatic damper, first looked on as a desirable attachment, has proved to be a most important factor in the successful operation of the superheater engine. During the first year's experience it appeared to make but little difference whether this damper was

operative or not, but it has been found that if neglected there is a gradual but serious deterioration in the ends of the superheater pipes. The structure of the metal becomes entirely destroyed and leaks occur at the return bends, and the metal in the pipes changes its structure until it can be broken in the hands. The damper is not difficult to maintain, simply requiring proper attention, but the design which has been used and which was introduced with the original Schmidt superheater is not satisfactory, and can certainly be very much improved, and its maintenance made easier.

36 The writer sees no reason whatever for abandoning a valuable and important principle such as the use of superheated team because troubles have been incurred through neglect in maintaining a small attachment which could easily have been attended to had its importance been appreciated, and after three years' experience feels justified in stating that if the dampers are properly maintained the trouble through the destruction of the ends of the superheater pipes will not occur.

37 With properly maintained dampers the next source of trouble is leakage at the connections of the superheater pipes to the headers. In the Schmidt design properly put up, this occurs but very seldom, and the majority of engines with this arrangement will run from shopping to shopping without attention. The objection that has developed in the Schmidt arrangement is that should any leakage occur, especially in the flanges attached to the upper rows of superheater pipes, it is practically necessary to take down all the flanges and make the joints afresh, and this takes considerable time with a corresponding loss in the service of the engine.

38 The greatest trouble has come from having to do this on account of the leaks occurring at the return bends caused by dampers not being properly maintained, but apart from this trouble the writer considers the Schmidt to be a satisfactory design, although the inability to take out any defective element without disturbing others is to his mind a great objection.

39 The Cole type of superheater has given considerable trouble from leakage at the joints between the sub-headers and the main header. While this may be overcome by a modification in the design, the number of defects which have developed has been most serious. The joints are probably loosened by the action of the weight of the superheater pipes working backward and forward when the engine is in service, and the loosening of the joints causes a leakage of steam across the face of the copper gasket and rapidly cuts it away. Arrangements are now being made to support the lower ends of headers

so as to prevent their movement, and it is thought that this will largely overcome the difficulty. No trouble is experienced in the joints between the superheater pipes and sub-headers, but the latter are difficult to take out one at a time without disturbing those adjacent, and thus in case of a defective superheater pipe it is generally necessary to make all the joints over again, which means considerable work.

40 The Vaughan-Horsey type gave considerable trouble at first on account of the fittings and union nuts being made of brass, which deteriorated in the heat of the gases, but since these parts have been made of steel, the trouble has been practically overcome, and on account of this design permitting any pair of superheater pipes to be withdrawn without disturbing another, a defective element can be taken out, the joints blinded, and the element replaced at the first convenient opportunity, which is of considerable advantage in round-house maintenance where engines are worked as hard and as continuously as they are in American practice.

41 In general the maintenance of superheaters has not proved expensive, but the troubles enumerated have led to annoying and inconvenient delays to power, which if not treated on their merits might be held to condemn the device, but when analysed, there seems to be no insuperable difficulty in remedying these, and with the proper remedy the writer firmly believes there is nothing about a superheater which should lead to its giving a less efficient service than a simple engine, and the slight additional expense is amply warranted by the saving obtained.

42 The smoke tubes have given but little trouble, in fact less trouble than the ordinary 2 inch or 2¼ inch tubes which they replaced. On some bad water districts where the small tubes have to be reset every 20,000 or 30,000 miles, the smoke tubes can be allowed to run through at least one resetting of the small tubes, which is probably due to the considerably better circulation and their greater thickness. Some difficulty has been experienced from the smoke-tubes stopping up with cinders especially with the Field-tube type of superheater which seems particularly bad in this respect. With the return bend type however on the majority of the roads there is no serious difficulty in this respect, although it is necessary to see that the tubes are properly and systematically blown out and kept clean. The expense in the labor involved in doing this is, however, negligible.

43 The maintenance of valve and piston rod packing is slightly greater on engines running with superheated steam than on simple engines, but with proper lubrication the difference is not serious. It is necessary to use hard close grained cast iron for the valve and piston

rings, but with suitable types of piston and valve stem packing there is practically no difference in the maintenance of simple and superheater engines.

44 In general, the writer believes that while it may be necessary to insist on the proper maintenance of superheaters the expense involved is not great, and with proper maintenance and the improvement in detailed design which experience is leading to, there will be practically no decrease in the mileage to be obtained from the superheater as compared to the simple engine, and that the additional cost of maintenance will be unimportant.

LUBRICATION

45 When engines equipped with superheated steam were introduced, it was considered necessary to use forced lubrication to the valves and cylinders and this belief led to considerable trouble owing largely to the various forced feed lubricators employed which did not work satisfactorily with their rapid wear and the small amount of attention they received from the enginemen. During the past year, however, it has been found that the ordinary hydrostatic sight feed lubricator is quite as satisfactory on engines using superheated steam as on those using saturated, but it is necessary with the oil at present employed to lubricate the cylinders in addition to simply lubricating the valves, as in common simple engines. The present practice is to use separate feeds to each end of valve and to center of cylinder near the top and with this arrangement no difficulty is experienced with lubrication, although the writer believes it would be advantageous to use a rather heavier valve oil than is at present customary.

CONCLUSIONS

46 The writer's experience with locomotives using superheated steam has not been free from vexations and annoying troubles, but it has on the whole been exceedingly satisfactory.

47 The troubles encountered are being overcome as experience develops their cause and the saving obtained is apparent in the reduction of the amount of coal used per ton mile on various divisions of the road as superheater locomotives are introduced. The additional capacity of the engines and the reduction of the work required of the fireman, enabling trains to be handled better, and the development of an engine which in extremely cold weather can be as easily maintained as a simple engine with an economy equal or superior to that of

a compound is an important advantage to any railroad working in northern latitudes.

48 So far as can be seen at present there is no valid reason for discontinuing the application of superheaters, and the writer expects that a considerable increase in the number in use will take place in the next few years.

THE ECONOMY OF THE LONG KILN

Tests on 7′ x 60′ and 8′ x 110′ Rotary Kilns Burning Natural Gas

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One of the most important steps in the manufacture of Portland cement is the burning or calcination of the raw material into clinker. Briefly described, the manufacture of Portland cement consists of three steps.

a Mixing and grinding the raw material.
b Burning.
c Grinding the resultant clinker.

2 Because of the high cost of fuel incident to its production, the burning is of vital importance. It is not our province to go into the history of the industry nor of the burning process in particular, and we will only say that the old vertical kiln gave way to the rotary kiln, because of the greater economy in labor, and up to the last two or three years the standard size of the rotary in use was about 6′ x 60′; today the preferred size is from 7′ to 8′ in diameter and varies from 60′ to 150′ in length, with the 100′ length kiln favored by the majority of the progressive manufacturers.

3 The kiln question, however, is still in a transitory stage, because of the keen competition and rivalry among the 95 different operating companies, and reliable data are not easily available. Just what sizes will be adopted as standard, if any, would be difficult to prognosticate at the present time. There are some of the manufacturers actually claiming from 400 to 500 barrels per day per 60 foot kiln, and some of the mills in the Lehigh district with 135 foot kilns have made as high as 750 barrels per day, but as to fuel economy, the information is not given out. Whatever fuel is used in the calcining of the raw material, approximately the same number of heat units must necessarily be

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required per barrel of clinker burned. The rotary kiln, even in its most improved installation, is not an economical proposition in point of fuel as its highest efficiency is less than 50 per cent. In other words, the heat actually consumed per barrel is generally more than double that actually required for the calcining and chemical processes involved.

4 In an ordinary 60 foot kiln installation, it generally requires 200 pounds of coal to burn one barrel of cement. Slack coal is generally used with the ash percentage varying from 5 to 15 per cent. Some manufacturers we believe have reduced this consumption to 85 pounds but the majority of the averages is about 120 pounds per barrel. This does not include the coal used in drying the raw materials and drying the coal itself and the coal required for power; these items will increase this amount to, say 150 pounds of coal per barrel, and

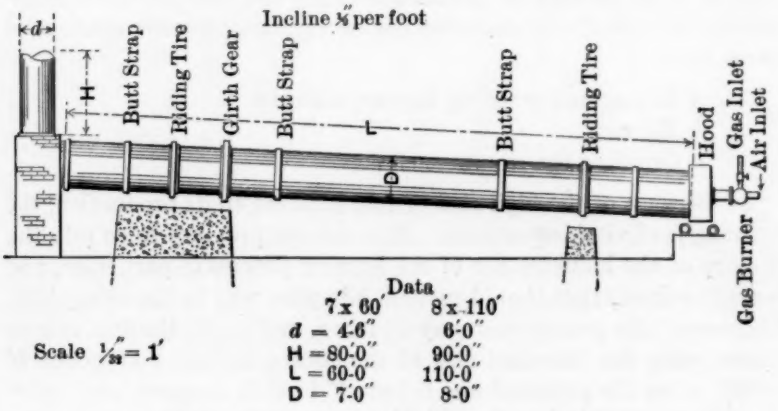

FIG. 1 SHOWING INSTALLATIONS OF KILNS

with the average price of coal at $2 gives an actual cost of fuel per barrel of 15 cents. The average cost of manufacturing Portland cement in a modern up-to-date plant in the Lehigh district is 70 cents per barrel, thus the fuel cost is 20 per cent, and this figure is a conservative average. According to the heat balance, the fuel consumption should be but one half of what is actually required in the best practice of today.

5 The burning of Portland cement by natural gas is an entirely different proposition, in point of installation, from the usual pulverized coal system. In the drawing above is given a typical installment. Gas is fed into a Kirkwood burner, of which there are many sizes. The burner is essentially a double cylinder with gas connection with the outer shell; a series of small perforated pipes perpendicular

to the axis of the cylinder and equal in length to the diameter of the inner cylinder allows the gas to flow into these pipes and out through the perforations into the inner cylinder, from whence it is blown by air furnished by a blower into the kilns. Fig. 2 shows a typical "Kirkwood burner." The gas is fed into the burner or mixer under an average pressure of about 2 pounds and the air pressure varies from 1 to 6 ounces in different plants.

6 The actual heat requirements in the burning process are as follows:

a Evaporations of moisture in dry mix.
b The driving off of the carbonates and sulphates.
c The heating of the material to clinkering temperature.

The losses occur as follows:

a Heating and evaporation of excess moisture.
b Heat contained in discharge of clinker.
c Heat radiated by kiln.
d Heat carried off by waste gases.

FIG. 2 THE GAS BURNER USED

7 The latter process is one of the greatest sources of loss in the older installations and was the chief cause of the bringing out of the "long kiln." In a 60 foot kiln, operating dry process, the stack temperature varies from 1000 to 1500 degrees F, in some cases they have been measured up to as high as 2000 degrees F. In the use of the long kiln these temperatures may be reduced in amount to 400 to 700 degrees F. and the fuel consumption correspondingly decreased. Prof. Carpenter's method of utilizing the waste heat from the ordinary 60 foot kiln under boilers is probably a more ideal method than lengthening the kiln, but for some reason, probably mechanical, it has been adopted in but one or two plants, and we understand that it is not a practical installation.

8 When natural gas was first utilized for burning in rotary kilns the number of cubic feet per barrel much exceeded that required at the present time, and even now when a kiln is first put into operation and until the lining is thoroughly "coated" the consumption per barrel is nearly double what it is after the kiln has been in operation for sometime.

9 The results of the tests given below are not from one day's operation but from several months' run. The heat distribution is given merely to show what work is still necessary before the heat requirements of the rotary kilns are reduced to as low a figure as is practical.

10 There is one big difference in a gas flame and the ordinary pulverized coal flame. The coal flame flares in a gradually increasing "cone" while the gas flame is similar to a "mushroom" and the heat zone is much nearer the discharge end of the kiln than in the cases of the coal burning system.

11 There are approximately 600 pounds of raw material required to produce one barrel of Portland cement clinker. A cubic foot of natural gas contains approximately 1000 British heat units.

12 The kilns below are operating on practically the same raw materials, under the same process and supervision. The proportions are, roughly, 75 per cent lime stone and 25 per cent shale:

TESTS

Size kilns	7′ x 60′ kiln	8′ x 110′ kiln
Date	Oct. 1, 1906	Nov. 1, 1906
Capacity of kiln, 24 hours	200 barrels	450 barrels
Cu.ft. gas actually required per barrel	12750	2000
Temperatures observed		
Stack gases	1300 degrees F.	450 degrees F.
2 feet inside nose ring	2400 degrees F.	
Temperatures discharged clinker	1380 degrees F.	1380 degrees F.
Atmosphere	70 degrees F.	70 degrees F.
Air pressure at burner in ounces per square inch	1.15	5
Diameter blow pipe	10 inches	16 inches
Size burner	12 inches	16 inches
Average speed of kiln	1 revolution in 1½ minutes.	1 revolution in 4 minutes.
Average horse power	12	20
Time required to burn 1 barrel	7.2 minutes	3.2 minutes
Number square feet surface in shell	1381	2765
Hood	100	172
No. lbs. dry raw material per barrel	610	610
Percentage water per barrel	33	33
No. lbs. clinker per barrel produced	384	384

Analyses

Natural gas

CH_4	97.63 per cent
C_2H_4	0.22 per cent
CO_2	0.22 per cent
CO	1.33 per cent
N	0.60 per cent

Limestone	Shale	Raw mix	Clinker	Limestone	Shale	Raw mix	Clinker
SiO_2		14.4	22.1	2.5	62.7	14.9	22.3
Fe_2O_3		2.3	3.6	2.2	26.0	7.6	10.7
Al_2O_3		4.9	7.9				
CaO		41.00	63.0	52.2	2.5	41.2	62.5
MgO		1.64	2.63	0.8	2.4	1.8	2.1
Loss		35.30		42.1	6.2	35.0	1.4

Specific heats

Air	0.2375
Waste gases	0.23
Clinker	0.2
CO_2, SO_2	0.24
Raw mix	0.2
Steam	0.48

Heats of combination

CaO	954.0 B. t. u.
MgO	1488.6

Heats of Decomposition

SO_3	1890 B. t. u.
$CaCO_3$	765

Number B. t. u. per cubic foot natural gas calculated from analysis	1088	1088
Number cubic feet air required to burn 1 cubic foot gas calculated from analysis—theoretical	9.39	9.39

DISTRIBUTION OF HEAT IN KILN PER BARREL CLINKER BURNED

		Per cent		Per cent
1 Evaporating and heating of 300 pounds water from temperature entering kiln to temperature stack; gases in B. t. u.	489,072	15.1	366,672	15.0
2 Heating 610 pounds dry mix from 70 degrees to 1000 deg.	113,460	3.5	113,460	4.6
3 Heating 384 pounds clinker from 1000 deg. to 2600 deg.	147,256	4.5	147,256	6.0
4 Heat radiated by 384 pounds clinker discharged at 1380 deg. and cooling to 70 deg.	120,729	3.7	120,729	4.9
5 Heat radiated by kiln shell and hood (calculated)	46,580	0.14	31,455	0.12
		Per cent		Per cent
6 Carried off by waste gases	777,325	24.0	202,000	8.3
7 Heat required to decompose $CaCo_3$	344,403	10.6	346,086	14.2
4 From below	15,504	0.06		
Total heat accounted for in kiln per barrel	2,054,529		1,327,258	
Unaccounted for, probably radiation and escaping in flames, shell, and hood	1,186,987	36.63	1,115,318	45.0
Total B. t. u. actually supplied	3,241,516		2,442,576	

HEAT DELIVERED TO KILN PER BARREL CLINKER BURNED

1	Contained in air entering through blow pipes in B.t.u.	1710	2,442
2	Contained in entering gas.	2000	2,012
3	Chemical action; liberated by combination of CaO	230,772	228,960
	MgO	15,034	4570
4	Liberated by CO_2 and SO_2 cooling from 1000 deg. to stack temperature.	−15,504	28,182
5	Produced by combustion of gas.	3,192,000	2,176,400
	Total heat in B. t. u. received by kilns.	3,241,516	2,442,576

13 It will be noted in the above that in the long kiln a 5 ounce pressure of air was maintained. The long kiln is a more recent installation and the question of air is one which has not been given the attention it deserves by the cement engineers. In several instances where the pressure and volume have been increased in the same kiln the output has been increased from 10 to 20 per cent. The maximum output of the long kiln is 600 barrels per day, but the figure given is maintained throughout the month, including shut downs, and is therefore, the one to be considered.

14 It will be noted that the stack temperature on the 60 foot kiln is about 1300 degrees, and this amounts to a loss of 24 per cent of the fuel supply to the kiln. It also means another loss through the heating of carbonates and sulphates, which are liberated at about 1000 degrees F. and which must be heated in the case of the 60 foot kiln and cooled in the 110 foot kiln to the temperature of the stack gases. Another means of utilizing the air which has been heated by the discharged clinker and blowing same into the kiln has saved, in some instances, as high as 10 per cent of the fuel. In other words, the fuel consumption has been decreased 10 per cent.

15 It is a question now whether or not the ideal length of the kiln should be between 100 feet and 125 feet. We have noted a kiln of the latter length and 7 feet 6 inches diameter operating under precisely the same conditions as the two above, and whose monthly average output barely equaled that of the 110 foot kiln. Of course the original cost of the latter kiln is double that of the 60 foot kiln but the labor per barrel in the burning department is one-half what it is with the 60 foot kiln, and while the horse power is proportionally more in the case of the long kiln the increased fuel economy of 25 to 35 per cent will more than compensate for the interest on the increased cost of the installation and the increased horse power.

EUROPEAN RAILWAY MOTOR CARS

By B. D. GRAY, PROVIDENCE, R. I.
Non Member

As a result of continued and consistent experimentation, covering a period of four years or more, conducted by numerous English and Continental railways, the self propelled railway car has been brought to such a degree of refinement that it has become an important and established factor in the transportation of passengers and light goods traffic. While its inception dates back many years—experiments along this line having been made as early as 1873—the successful development of the self contained car is quite recent. Owing partly to the crudity of early designs, but largely to under-estimation of its possibilities and lack of appreciation of the necessity for frequent and rapid train service, and because the demands of the traveling public were not nearly so exacting as at present, the early experiments were probably premature; but the phenomenal growth of our large cities, the grouping of commercial interests, and the ever present desire for home comforts, have removed residence districts from business centers, and brought about the necessity for efficient suburban and interurban transportation facilities. Greater demands upon business men's time have likewise contributed to the necessity for rapid transit. The influence of metropolitan activity is felt in the smaller cities and provincial towns, and extends even to the most remote country districts.

2 In the United States, electricity has been widely adopted as a motive power, and has met with marked success, the demands for quick and reliable service. Electrification of existing steam roads and the building of new electric lines have not been taken up so generally in Europe, and it is therefore only natural that the engineers of those railways should look for the solution of the frequent service problem in a vehicle which might be adapted to existing conditions with no expenditure for equipment other than that for the vehicle

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itself. This condition of affairs probably influenced recent builders of motor cars in selecting steam as a motive power, although its predominance at the present time is due chiefly to its low fuel cost and great flexibility.

3 Numerous English and Continental railway companies have permanently established motor car service on their lines in different localities with marked success. The practicability of the self contained car for certain kind of service can no longer be doubted, nor is its field so limited as might be generally supposed. One may see such cars operating on unimportant branch lines as feeders to trunk line trains; on main lines through thickly populated districts carrying passengers and luggage to and from the more important towns served by express trains; on suburban lines in competition with both trolley cars and steam trains; on an entire railway system where there is no other means of transportation except for heavy freight.

4 Its adoption permits better service with greater frequency at lower cost of operation than is possible with the ordinary steam train, comprising a locomotive and one or more passenger coaches or combination cars, the lower operating cost being due chiefly to decreased fuel consumption and a reduction in the train crew. Motor car equipment is cheaper to install than ordinary train equipment, therefore fixed charges on the investment are correspondingly less. Maintenance charges on rolling stock are about the same in both cases, but track maintenance is less where motor cars are used because of decreased weight.

5 As compared with electric railways for interurban service where current is supplied from a central station, the relative economy depends chiefly upon the frequency of the service. Taking into account the cost of equipment, installation, operation, current losses, etc., it is fair to assume that where cars are to be run at 30 minute intervals or less, the electric railway is the more economical, but where car or train intervals are greater than 30 minutes, the balance is in favor of the self propelled car.

6 The following list comprises the principal railways operating motor cars, the motive power of these cars, and type:

NAME OF RAILWAY.	MOTIVE POWER	SYSTEM
	ENGLAND	
Great Western	Steam	Great Western
Taff Vale	Steam	Taff Vale
London & South Western	Steam	L. & S. W.
Lancashire & Yorkshire	Steam	L. & Y.
North Eastern	Petrol-Electric	N. E.

NAME OF RAILWAY	MOTIVE POWER	SYSTEM
FRANCE		
Paris, Lyon & Mediterranean	Steam	Purrey
Paris, Lyon & Mediterranean	Steam	Serpollet
Paris, Orleans	Steam	Purrey
French State	Steam	Purrey
BELGIUM		
Belgium State	Steam	Belgium State
SWITZERLAND		
Swiss Federal	Steam	Serpollet
Swiss Federal	Gasolene	Ger. Daimler
AUSTRIA		
Austrian State	Steam	Komarek
HUNGARY		
Hungarian State	Steam	Ganz
Arad and Csanadar	Gasolene	Ger. Daimler
Arad and Csanadar	Steam	Ganz
Arad and Csanadar	Gasolene-Electric	Weitzer

LONDON & SOUTHWESTERN RAILWAY

7 The London & Southwestern Railway was one of the pioneers in the movement for self-contained cars, and in 1903 placed a steam car on their line between Fratton and South Sea. This car was equipped with small cyclinders and vertical boiler, and while not capable of high speed or quick acceleration, the results obtained were satisfactory from the standpoint of economy of operation, and probably encouraged, more than anything else, other railways to take up this problem. This car has a total length of 50 feet, and seats 40 passengers. The cylinders are inclined, driving the leading pair of wheels only.

GREAT WESTERN RAILWAY

8 One of the most satisfactory cars in operation abroad at the present time is the one developed by Mr. Churchward, chief engineer of the Great Western Railway of England. In the neighborhood of sixty of these cars are in service on various parts of the Great Western system, and others are in course of construction. They combine, to a remarkable degree, many of those qualities essential to success:

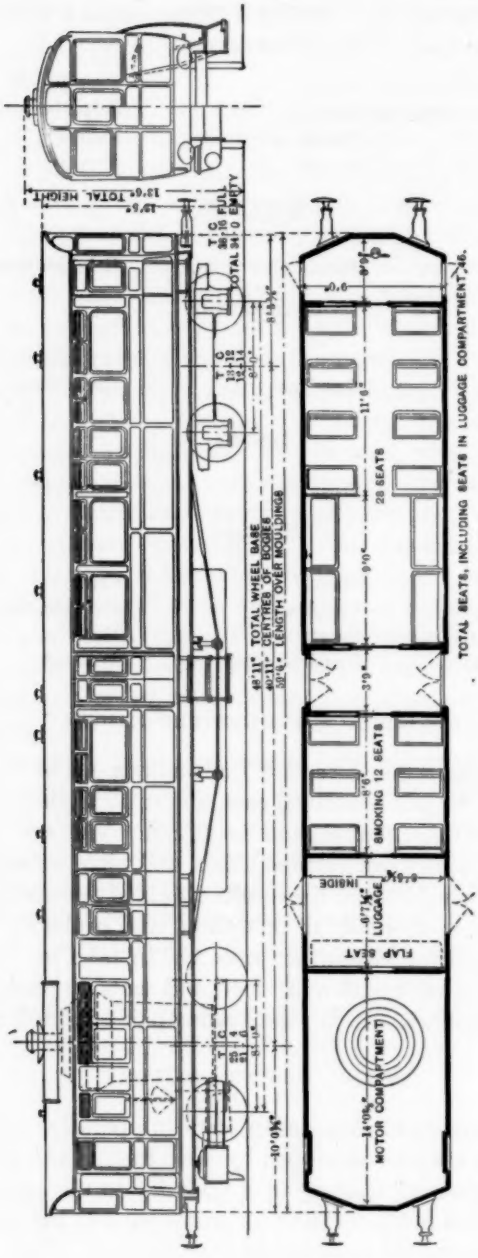


FIG. 1 TYPE OF MOTOR CAR COSTING ABOUT $9000

large seating capacity with only moderate weight, flexibility of control, reasonable speed and acceleration, reliability, low maintenance and fair operating costs.

9 The boiler is of the vertical, fire tube type, with no superheater, supported directly on the frame of the power truck, and serving as a center pin by transmitting the driving effort to the sills of the car through flat springs. It is enclosed within a compartment of the car body, about 14 feet long, which contains the coal bunkers, operating levers, etc. As the car is arranged to run in both directions and controlled from both ends a stoker is employed in addition to the driver. Aside from attending to the fire it is his duty to regulate the cut off when the driver is at the other end of the car, as only brake and throttle connections are provided there.

10 The motor consists of two single expansion cylinders 12″ x 16″, coupled direct to the rear driving wheels, which in turn are coupled to the front drivers. Walschaert valve gear is used.

11 Air brakes are provided, the usual form of steam actuated automatic pump being used to supply the air. The water supply is carried in tanks hung beneath the car body midway between the trucks.

12 As an indication of the reliability and commercial success of these cars, the following instance of service conditions may be cited: Two motor cars and four or five trailers are used on the main line of the Great Western between Chalford and Stonehouse, a distance of about seven miles. The railway at this point runs through what is known as the Stroud Valley, a thickly populated section comprising in all about 40,000 inhabitants in the nearby towns and outlying districts. The motor car schedule provides, on an average, fourteen round trips per day (a total of about 200 miles) so arranged as to run these cars between through trains, both passenger and freight. There are ten stops in the seven miles, and the running time each way is from 23 to 25 minutes.

13 Stroud, the most important town in this section, is located about midway of the run, and is served by express trains. The frequent motor car service provides an attractive means of reaching express trains in addition to local transit, and has resulted in a material increase in traffic in that section. Ordinarily, one motor car suffices, but on Saturdays, Sundays, and holidays, when traffic necessitates, both cars are used, and frequently with one or two trailers.

14 Fares range from 2 to 8 cents, depending upon the distance, the average weekly receipts being about $300.

15 These cars are capable of a maximum speed of 55 miles an

hour, although the average running speed is 30 to 35 miles an hour, Their maximum acceleration is about one mile per hour per second.

16 The original cost of the type of motor car shown on Fig. 1 is about $9000, and the cost of operation, aside from the guard's pay, is 13 cents per car or train mile, including trailers, for the service above referred to, the coal consumption being about 20 pounds per train mile. The wages paid to men operating these cars are about as follows: guard, 6 shillings per day; driver, 7 shillings per day; stoker, 3 shillings 6 pence per day.

17 The Great Western Railway Co. are now building a series of trains for service similar to that described above, consisting of a small locomotive and four cars, two at each end with the locomotive in the middle. In this case, the stoker only remains on the locomotive, the driver controlling the train from either end.

TAFF VALE RAILWAY

18 The Taff Vale Railway has built a number of cars for their own use and for other railways, the designs varying slightly to suit the conditions of the different roads. Those used by the Taff Vale Railway are similar to the Great Western car in most respects, the chief difference being in the construction of the boiler, which is of rather peculiar design. It is of the fire tube type, and consists practically of two horizontal barrels placed on either side of a central furnace, the hot gases passing horizontally through the fire tubes to smoke boxes at the outer ends, and from there through flues to a central stack. The boiler is placed transversely with reference to the car body, and rests directly upon the truck frame just aft of the forward axle, which is the driving axle. The forward end of the car body is pivoted on the power truck, but does not include a compartment for boiler, etc., as in the case of the Great Western.

19 The power truck is self contained, and a cab is provided for the driver similar to that of a small locomotive. The cylinders are placed outside, and the valves operated by an ordinary link motion with rocking shaft. The car is heated by steam from the engine with warmers of acetate of soda, and light is furnished by the Pintsch system of oil gas. Both hand and vacuum brakes are provided. The conductor can communicate with the motorman by means of an electric bell, and also shut off steam and sound the whistle. This car is capable of running 35 miles per hour on the level, and will ascend a $2\frac{1}{2}$ per cent grade at 20 miles per hour. It may be operated from either end, and all operations, except starting, can be performed from the guard's

compartment. It is claimed that it is possible to remove the engine from the car body in 20 minutes.

Latest type of Taff Vale car:

Over all length, about 70 feet
Seating capacity, 43
Total weight, 42 tons
Weight on power truck, 30 tons
Cylinders, bore 10½ inches; stroke, 14 inches
Total heating surface of boiler, 465 square feet
Grate area, 10 square feet
Capacity of water tank, 550 gallons
Steam pressure, 180 pounds
Tractive force, 5292 pounds
Boiler has 232 1¾ inch tubes

LANCASHIRE & YORKSHIRE RAILWAY

20 The Lancashire & Yorkshire car is similar to the Taff Vale car in this respect, that the forward end is pivoted on the power truck, although it is necessary for the underframing to project some distance forward of the car body to reach the pivotal point, owing to the fact that the driver's cab extends somewhat to the rear of the rear axle of the power truck.

21 The boiler is of the usual locomotive type with horizontal fire tubes. This engine is practically a small locomotive with drivers coupled.

Heating surface:
199 fire tubes 1¾ inch outside diam., area.....455 square feet
Fire box area..... 54 square feet
Total .....509 square feet
Grate area..... 9.4 square feet
Water capacity.....550 gallons
Boiler pressure.....180 pounds
Coal..... 1 ton
Two cylinders, bore 12 inches, stroke 16 inches

NORTH-EASTERN RAILWAY

22 About three years ago, the North-Eastern Railway of England put into service two "petrol-electric" cars on a short line running out from Scarborough. Owing to the fact that traffic on this line is heavy during the summer season only, these cars are laid up during the winter, and have therefore not been in continuous service. One gallon of gasolene to 3½ car miles is claimed for them, but the maintenance charges must necessarily be high.

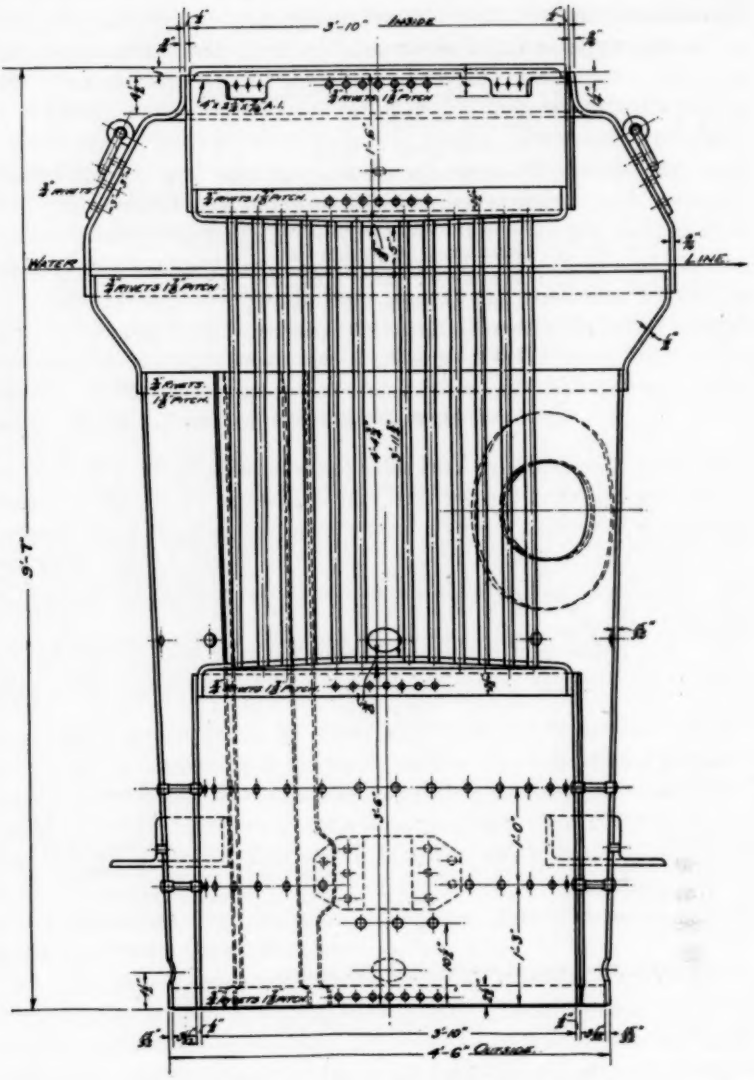


FIG. 2 GREAT WESTERN BOILER

Heating surface:

420—1¾" fire tubes—area 613 sq. ft.
Firebox, 46 sq. ft.
Total, 659 sq. ft.
Grate area, 11.54 sq. ft.
Steam pressure, 160 lbs.

23 The power plant consists of a 4 cylinder horizontal opposed Wolsley engine, 8½″ x 10″, 85 b. h. p. at 420 r. p. m., direct connected to a compound wound, separately excited generator, of 55 kilowatt capacity, which furnishes current to two 50 horse power electric motors, of the ordinary railway type, on the leading truck.

24 The exciter of 3.75 kilowatt capacity is mounted above the main generator, and driven by a belt from the flywheel of the engine. In addition to exciting the fields of the generator, it is used to charge a storage battery which supplies current for lighting the car, starting the generator and gasolene engine, and for a small automatic compressor motor, which supplies air for the whistle. The battery and the compressor outfit are suspended beneath the car body. The engine and main generator are very cumbersome and heavy, and occupy practically one-third of the total length of the car. The total weight including, 60 gallons of gasolene and about 100 gallons of cooling water, is 35 tons, of which 22 tons are carried on the power truck.

25 Radiating pipes located above the engine room, and supplied with air by a horizontal fan, in addition to that due to the motion of the car, serve to cool the jacket water. For extremely warm weather, an additional coil extending along the roof is provided and pipes are also arranged inside the car to be used for heating in cold weather. Electric brakes are used, the current being supplied by the motors acting as generators.

26 Controlling apparatus is provided at both ends of the car, and only two men are required to operate—motorman and guard. The wages paid are about 7 and 6 shillings per day, respectively.

27 The complication of this system, the multiplicity of parts, and the excessive weight give a rather unfavorable impression. The combined efficiencies of the generator and motors must of necessity be low, and their use can only be reconciled with the extreme flexibility of transmission necessitated by a large unwieldly gasolene motor. As this particular type of car has not been perpetuated by the original builders and users, it may be safe to assume that it is not entirely satisfactory. It is the author's opinion that its indifferent success is due to the enormous size and weight of the power plant throughout, as a number of cars embodying practically the same principles, but of much lighter construction, have been in successful operation in Hungary during the past three years.

FRENCH RAILWAYS

28 Numerous experiments have been made on the different French railways, including the Paris-Orleans; Paris, Lyons & Medi-

terranean; Northern; Western and the State railways, with various types of cars, but the most successful at the present time, and the one being almost universally adopted, is that of Purrey, of Bordeaux, and although differing in minor structural details, the power plants of the Purrey cars as built by the different railways are practically the same. There is also a slight variation in the size, weight, and arrangement of cars to best meet the requirements of the different roads, but that of the Paris-Orleans Railway is fairly representative of all the cars used in France.

PURREY CAR (PARIS-ORLEANS RAILWAY)

29 The car body has a total length of about 60 feet, and seats 30 third-class passengers in three compartments, and 25 first-class passengers in 2½ compartments. In addition to this, there is a baggage compartment at the forward end 11 feet 6 inches long and extending the entire width of the car, 112 inches. The forward end is pivoted on a power truck, the rear end being carried upon a single axle. The power truck, which carries the boiler, motor, fuel, water, etc., has two axles 126 inches apart, the rear wheels only being used for driving. The weight of this truck is 14½ tons, of which about 7 tons is on the rear axle. The total weight of the car complete is in the neighborhood of 35 tons.

BOILER

30 The Purrey boiler is tubular, its general construction being illustrated by Figs. 3a and 3b. Two drums are provided, the lower one of rectangular section and made of cast steel, the upper, cylindrical and of cast iron. The lower drum is divided into three compartments, two of which are provided for water, the third for superheated steam. The outer and lower compartment is connected with the upper drum by two large return pipes. It is also connected with the intermediate compartment of the same drum by 41 U shaped tubes. The feed water entering the lower compartment is thus heated in passing through these tubes, which are in direct contact with the flame. From this point, the water rises through a series of U shaped tubes to the upper drum, and the steam thus formed is returned from the upper drum, in which the water level is maintained at about the median line, through a number of similar tubes to the third compartment of the lower drum, from which it is taken to the motor. The steam is highly superheated in these tubes, the average temperature of superheat being from 750 to 900 degrees F. At first, considerable trouble was experienced with the burning out of the superheater

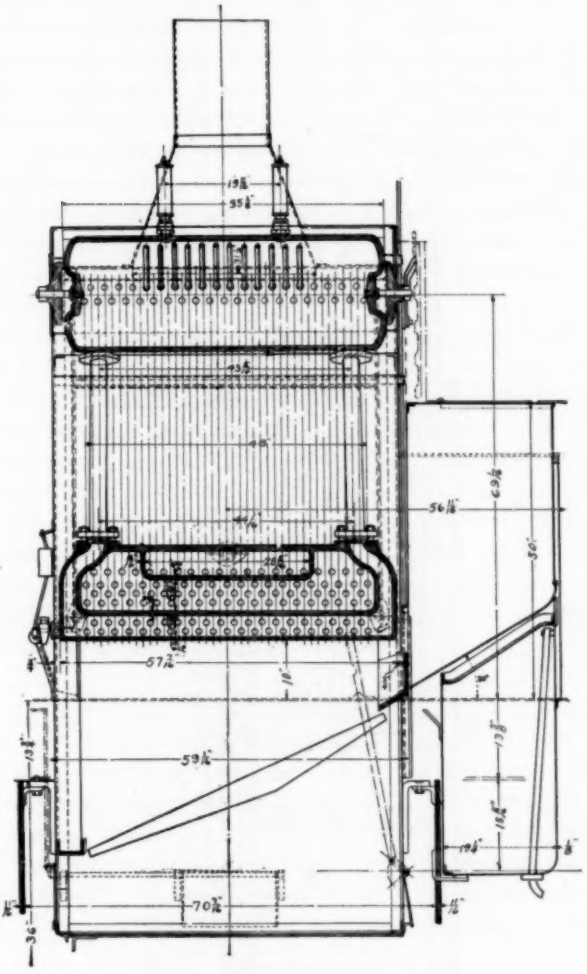


FIG. 3a PURREY BOILER

Total capacity, 118 gallons.
Steam pressure, 284 lbs. per sq. inch.
Number of short water tubes, 41.
Number of long water tubes, 29.
Number of superheater tubes, 12.
Inside and outside diameter of tubes, 26 x 30 mm. (1″ x 1 $\frac{3}{16}$″)
Inside and outside diameter of lower end of superheater tubes, 22 x 30 mm. ($\frac{7}{8}$″ x 1 $\frac{3}{16}$″)
Total heating surface 255, sq. ft.
Superheater surface, 80 sq. ft.
Grate area, 11.62 sq. ft.
Outside diameter of upper drum, 20″.
Total length of upper drum, 53″.

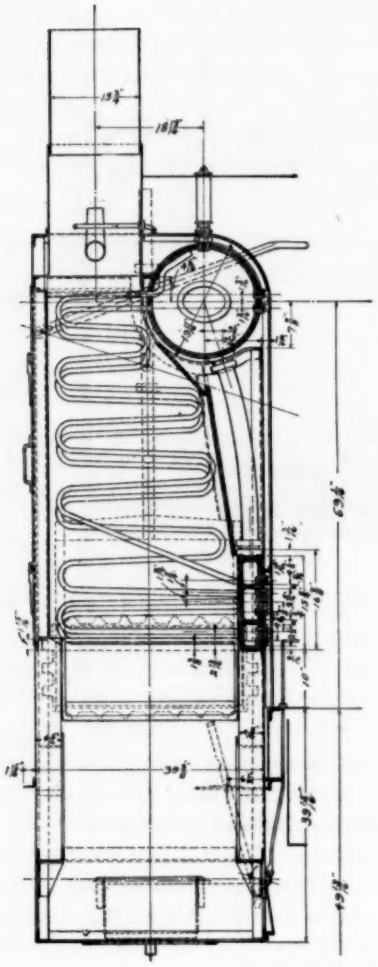


FIG. 3b PURREY BOILER

tubes in the lower coils which were in the most direct contact with the flame. This difficulty was overcome by eliminating two coils and increasing the thickness of the tubes at that point. Originally all tubes were 2 mm. thick, but those referred to were increased to 3 mm.

31 An inclined grate is provided, and the fuel, coke, feeds from the bunker attached to the side of the boiler, automatically, or practically so, the only attention necessary on the part of the driver being to regulate the supply by means of a vertical sliding door, operated by a lever, at the point where the bunker communicates with the furnace. Where price is not prohibitive, kerosene might be used to advantage, and would permit more perfect control of fire, and thus avoid burning out tubes.

32 An arrangement is provided for automatically maintaining a constant water level, consisting of a float inside the upper drum connected through a stuffing box to a valve in the steam line running to the feed pump, the idea being that as the level of the water is lowered, the steam valve opens and the pump supplies water until the level has reached that point at which the float closes the steam valve. This was found to be very unsatisfactory as the stuffing box, if made tight enough to prevent leakage, created so much friction that the apparatus would not work. It was therefore necessary to depend upon the driver to maintain a correct water level, Blake double acting feed pumps being provided for this purpose.

MOTOR

33 The motor is 4 cylinder tandem compound, high pressure $6\frac{5}{16}$ inches diameter, low pressure $8\frac{11}{16}$ inches diameter, and the stroke $8\frac{7}{8}$ inches, rated at 260 horse power at 650 revolutions per minute. A by-pass valve is provided to admit high pressure steam to the low pressure cylinders for quick acceleration and unusually heavy pulling. Ordinary D type valves are used, operated through Stephenson link motion.

34 In this design, the motor is attached horizontally to the frame of the car, and its power transmitted to the rear axle by two toothed chains of special construction, similar to the Renold and Morse silent type. All the working parts are enclosed in a dust proof case, and lubricated principally by splash. The motor is accessible through a trap door in the floor of the baggage compartment, and any ordinary adjustments can be made from this point. A door is also provided opening into the baggage compartment through which the boiler tubes may be inspected, thus rendering the most delicate parts of the

mechanism readily accessible. Should it be necessary to overhaul the boiler or motor, the power truck may be removed from the body of the car in 20 minutes and another substituted in its place. Westinghouse air brakes and hand brakes are used. Steam whistle is provided.

35 The Paris-Orleans road have 10 cars and 12 power trucks, and have been able to keep the 10 cars in service practically all the time by having the two extra trucks in reserve. Replacing boiler tubes is a comparatively simple matter. By removing plugs in the two drums on the opposite sides from where the tubes enter, the tubes are accessible either for driving out or expanding.

36 As a rule, one or two trailers are attached to these motor cars, the average weight of the train being 50 tons. The fuel consumption for such a train is about 21 pounds of coke per mile.

37 This car is arranged to run in one direction only, except for backing up, and the crew consists of only the driver and one man in the baggage compartment, tickets being taken at the stations by inspectors. It is geared rather high, and is capable of running at a speed of about fifty-six miles per hour. Its acceleration, however, is not so good as that of the Great Western car.

38 The Orleans road has instituted a motor car service between Bourges and Saincaize, a distance of 59 kilometers (37 miles), the run being made in 70 minutes, including eight stops. Sufficient fuel and water capacity are provided for a run of 50 kilometers. The cost of operation per train mile is about 7 cents, itemized as follows, train weighing approximately 50 tons:

Fuel (coke)	$0.0355
Kindling wood	0.0013
Oil	0.0022
Water	0.0005
Repairs	0.004
Driver's wages	0.0264
Total	0.0699

39 This of course does not include the wages of the guard, nor any of the overhead expenses. It is probable, however, that the cost of operation of this car is somewhat less than that of the Great Western.

40 The Purrey system has been used for a number of years on different tramway lines in the city of Paris, but for this service it has been found that the single expansion engine gives better results than the compound, and also that there is no advantage in having a vari-

able cut off, owing to the frequency of the stops, the speed of the motor being controlled entirely by the throttle valve.

ARAD CSANADAR RAILWAY OF HUNGARY

41 One of the most interesting examples of successful operation of railway motor cars on a large scale is that of the Arad Csanadar Railway of Hungary.

42 Three years ago a Ganz steam car was put into service on this road in an experimental way, and the results were so satisfactory that the management decided to replace their locomotive and train service, for passenger and light goods traffic, with the self-propelled car, and have gradually added to their motor car equipment until now they have a total of 37 cars of which 4 are Ganz steam cars 35 horse power of the de Dion system; 22 are gasolene-electric 30–35 horse power of the de Dion Bouton system, constructed by Johann Weitzer; 10 are gasolene-electric 70 horse power of the de Dion Bouton system; 1 is gasolene 40 horse power (German Daimler.)

43 The total length of this railway is about 400 kilometers, single track, running for the most part through a sparsely populated agricultural district where conditions are conducive to economical operation, as the average Hungarian peasant is not very fastidious nor exacting in the matter of luxuriously furnished cars or rapid transportation. Their cars are of very light construction, and being run at low speed, require small power plants in which the fuel consumption is comparatively low. Only the heavy freight traffic is handled by steam locomotives, and in 1906 the motor cars covered a total of about 1,000,000 miles, in most cases hauling from one to four trailers.

44 The improved service offered by the motor car has stimulated traffic in that section to such an extent, that within the past two years it has doubled. One of the most remarkable features in connection with the success of this railway is the extremely low fares, which average about $\frac{1}{3}$ cent per mile, and yet the road pays about $8\frac{1}{2}$ per cent on the investment of $6,500,000 after paying 19 per cent of the total receipts to the government as a tax. The comparative cost of operation of the different cars owned by this road are given in the following table, which represents an average for 1906. No data was obtainable on the Daimler gasolene car.

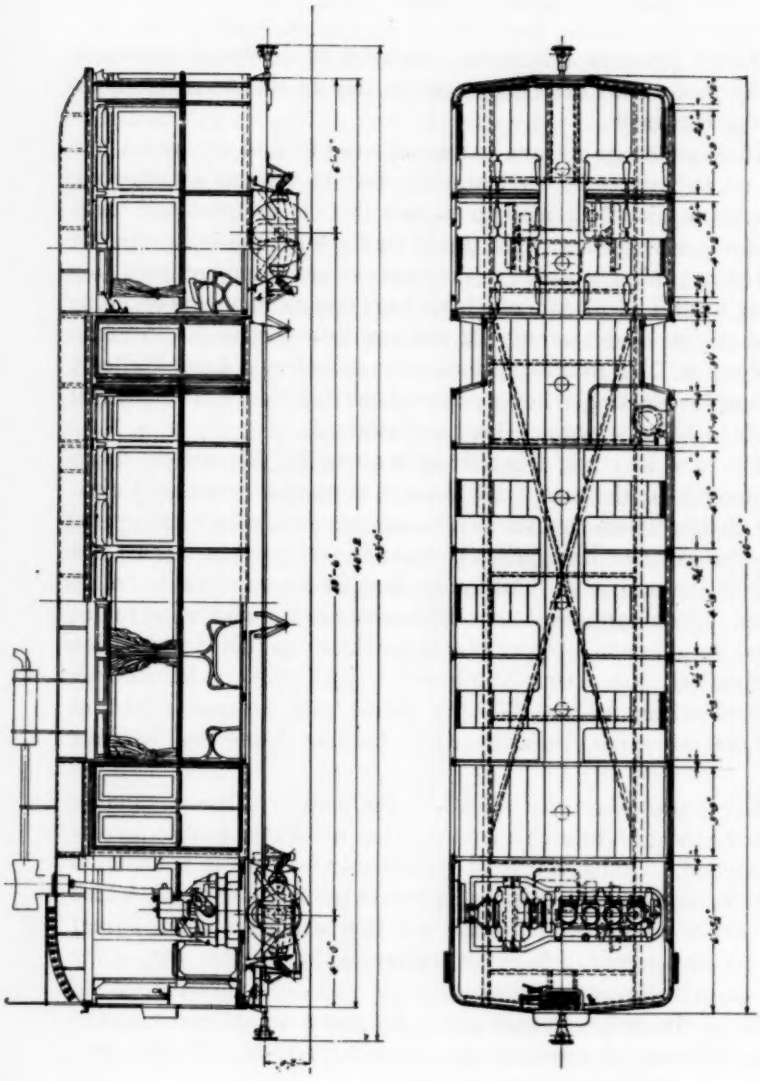


FIG. 4 ARAD CASANADAR 70 HORSE POWER CAR, GASOLENE—ELECTRIC

Over all length, including buffers, 43 ft.
Wheel base, 28 ft.
Seating capacity, first class, 12; second class, 24
Brakes, Bocker air brake and hand brake, 8 shoes.
Lighting, acetylene.
Heating, warm water.
Total weight, 17 tons.
Greatest permissible weight per axle, 10 tons.

TABLE 1 COST OF OPERATION

Type of Car	Fuel per train mile	Fuel	Oil	Sundries	Labor	Total labor and material	Maintenance Labor and material	Total cost
Ganz 35 h. p.	Coke 9.6 lbs.	0.034	0.0084	0.00058	0.0192	0.06218	0.0128	$0.07498
Gas.-elec. 70 h. p.	Gasolene at 10c gal. 2.11 lbs.	0.034	0.0066	0.00064	0.0144	0.05564	0.017	0.07264
Gas.-elec. 35 h. p.	Gasolene at 10c gal. 1.61 lbs.	0.026	0.0028	0.00074	0.0115	0.04104	0.0163	0.05734

GASOLENE ELECTRIC CAR (WEITZER)

45 Fig. 4 illustrates the general arrangement of one of the larger gasolene electric cars used by this railway. It is equipped with a 70 horse power gasolene motor direct connected to a 45 kilowatt generator, which supplies current to two ordinary railway type motors attached to the two axles. The usual series parallel controller is provided for starting. After the car is once under way, its speed is almost entirely controlled by the throttle of the gas engine. At the right of the electric controller are two smaller levers, one of which connects with the throttle, and the other with the spark advance mechanism. In addition to these, there is a small rheostat provided within easy reach of the operator, which serves to vary the field strength of the generator, and thus gives an additional means for controlling the car during the acceleration period. Controlling apparatus is pro vided at only one end of the car, as it is intended to run in only one direction except for shunting. Bocker air brakes and hand brakes are provided, air being supplied by a small compressor driven from the outer end of the armature shaft. An air whistle is used. Acetylene gas is used for lighting. Coils are provided along the sides of the car body for heating, the jacket water from the motor being used for this purpose. In warm weather the jacket water is passed through a coil of tubes on the roof at the forward end where it is exposed to the air.

46 The space occupied by the power plant is considerably less in proportion to the length of the car than that of the Great Eastern, although the systems are practically identical in principle. Its acceleration is very good indeed, and its maximum speed is about 35 miles per hour without trailer, and with two trailers about 25 miles per hour. More than two trailers are never used with the 70 horse power car, as it is used for express service, but the smaller cars

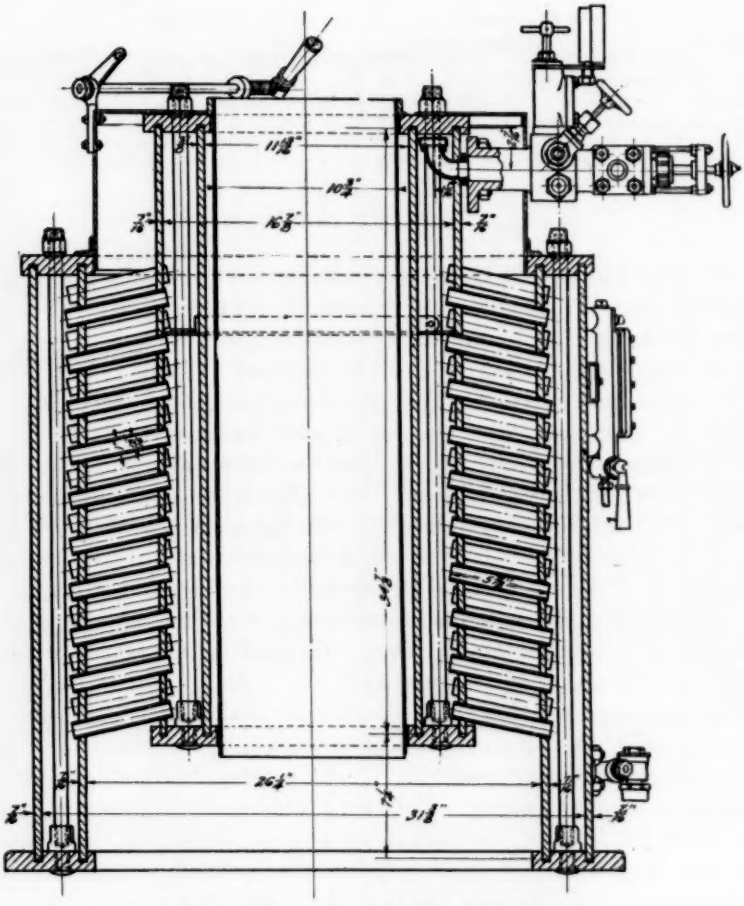


FIG. 5 35 HORSE POWER GANZ BOILER

702 Steel tubes, 25 mm. o.d., 21 mm. i. d.
Heating surfaces: Water, 62 sq. ft.; steam, 29 sq. ft.; total, 91.
Grate area, 3¼ sq. feet.
Steam pressure 280 lbs. per sq. inch.,
Fuel, charcoal or coke.

equipped with 35 horse power motors which run very much slower, frequently haul as many as four trailers. It is claimed by the engineers of this road that 65 per cent of the motor's power is delivered at the wheels. In general very satisfactory results are obtained and the car is admirably adapted to their conditions.

GANZ CAR

47 The Ganz cars are manufactured in 3 sizes, 35, 50 and 80 horse power. The general arrangement is the same in all three, the boiler being placed in a compartment at the forward end of the car, together with fuel bunker, feed pumps, and controlling apparatus. The motor is placed horizontally on the leading truck, and drives the rear axle through spur gears. It is supported in the usual electric railway motor style, one end being swiveled about the axle, and the other supported elastically from the truck frame. Control is provided at only one end, and only one man is required to operate the car. The 35 horse power car has a seating capacity of 22 first-class and 12 second-class passengers. Its over all length is about 35 feet. A speed of 35 miles per hour is claimed for this car with a fuel consumption of 5.3 to 7.2 pounds of coke per mile. The same consumption is claimed with trailers weighing from 35 to 40 tons at a speed of 12½ miles per hour. All cars manufactured by this company are fitted with both hand and air brakes, Bocker and Westinghouse being used. They are steam heated and provided with steam whistles.

35 H. P. BOILER PLATES.

48 The Ganz or de Dion boiler consists of four concentric cylinders with headers which are held in place by bolts, forming two annular water spaces joined together by means of slightly inclined steel water tubes, 25 mm. outside diameter and 2 mm. thick. Within the inner cylinder is another cylinder of slightly smaller diameter through which the fuel is fed to the grate below, the flame and hot gases passing around the water tubes to the chimney. It is claimed that these boilers are very easy to dissemble and clean because of the removable heads, although the replacing of gaskets is a rather troublesome matter. As a rule they require cleaning once every four or five months.

MOTOR

49 Ganz motors are two cylinder cross compound, the one used with the 35 horse power boiler having cylinder diameters of $4\frac{9}{16}$ inches

and $6\frac{11}{16}$ inches and common stroke of $4\frac{3}{4}$ inches. Two steam operated feed pumps are provided, one being held in reserve.

50 The 80 horse power car has a total length of 46 feet, seats 47 passengers, weighs 23 tons, and is capable of climbing a 1.6 per cent grade, with two trailers weighing 12 tons each, at a speed of 25 miles per hour. One peculiar feature of the Ganz system is the double gear reduction between the motor and the axle. Two spur gears are mounted loose on the crank shaft between the two cranks and meshing with gears keyed to the axle. A jaw clutch positively driven is provided between the driving gears, and so arranged as to engage either one or the other when moved along the shaft. The ratio of reduction is about 2 to 1. As a rule, the low gear is used when the trailers are attached and for heavy grades.

51 Ganz cars are used rather extensively in central Europe, although in certain localities their boilers have not been entirely satisfactory because of the frequent cleaning necessary, due chiefly to impure water. Both steam and water space are somewhat limited and rather close attention on the part of the operator is required to keep the water level at the correct point.

52 The Hungarian State railways tried the Ganz car, but their experience was not entirely satisfactory for the reason that the quality of water available necessitated frequent cleaning of the boiler.

SERPOLLET CAR

53 The Serpollet system differs from the Purrey and Ganz types chiefly in that the boiler is of the flash type, and kerosene is generally used as fuel. A very high degree of superheat is obtained, reaching even 1200 degrees F. which, together with the incrustation attending the use of more or less impure water is conducive to the burning of tubes. The experience of the Paris, Lyons & Mediterranean Railway with this type of car has been rather unsatisfactory, because of tube troubles, and the Purrey car is now being adopted in its place.

KOMAREK CAR

54 The Komarek car, manufactured by F. X. Komarek, Vienna, and used to some extent by the Austrian State railways and several of its branches, is one of the most rational in design of all in use abroad. Its builders may have erred slightly on the side of weight, but it shows remarkable economy and unusual freedom from repairs and troubles

of all kinds. Although built in several sizes and many forms, the following type may be considered as representative:

Car body, total length, 51 feet
Seating capacity, 35
Baggage room, 44 inches by 96 inches
Length of boiler and fuel compartment, 10 feet
Weight empty, 20 tons
Coal capacity, 1100 pounds
Water capacity, 420 gallons
Motor, 2 cylinder cross compound, outside cylinders
Cylinder diameters 10 inches and 15 inches. Stroke, 16 inches

55 Steam feed pumps of standard pattern are used, and a locomotive air pump is provided for supplying the brakes. Hand brakes are supplied as well. The cars are steam heated and lighted with acetylene. A steam whistle is provided. This car is capable of running at a speed of 25 miles per hour on a level while hauling trailers comprising a total of 50 tons. The operating cost is said to be about 5 cents per train mile exclusive of the guard's pay, with coal costing $3.25 per ton.

COST OF OPERATION PER MILE OF KOMAREK TRAIN OF 50 TONS

Coal	$0.0253
Oil	0.0014
Labor	0.0046
Maintenance:	
Material	0.0011
Driver	0.016
Total	0.0484

56 In general, the arrangement of the four axle car is similar to the Purrey with the forward end of the body supported on the power truck. Other types with two and three axles have the boiler in a compartment at the forward end of the car body, supported by the main body frame. The motor is practically a small cross compound locomotive with outside cylinders, driving on one pair of wheels only. A vertical water tube boiler of special construction, shown in Fig. 6, is used. To provide for expansion, the inner shell is corrugated, and the tubes are accessible for cleaning and renewal through plugs and manholes in the outer shell. A superheater coil is placed in the upper part of the furnace, and heated by the exhaust gases, the degree of superheat averaging about 300 degrees F. This car is arranged to run in both directions, and when running backward, the guard remains on the rear platform and signals the driver at the other end by

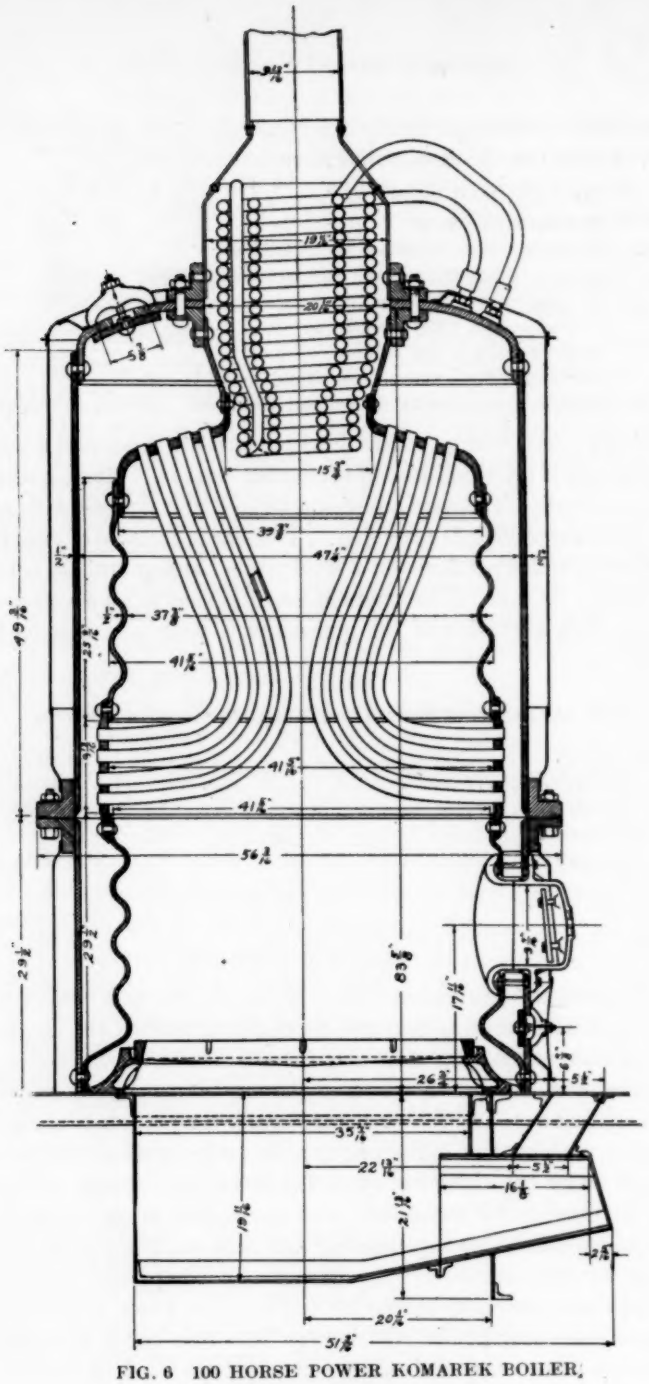


FIG. 6 100 HORSE POWER KOMAREK BOILER.

Heating surface, 215 sq. ft.
Superheater surface, 32 sq. ft.
Total heating surface, 247 sq. ft.
Grate area, 7 sq. ft.
Steam pressure, 210 lbs.

means of a modified system of ship signals. Air and hand brake control, and also means for closing the throttle, are provided on the rear platform so that the guard may stop the car independently of the driver.

GERMAN DAIMLER GASOLENE CAR

57 This type of car has been used in considerable quantities on some of the smaller German railways, notably the Württemburg State Railway and on the Swiss Federal Railway. It is a comparatively small car having a total length of 33 feet with a seating capacity of 36. It is equipped with a 30 horse power Daimler four cylinder ($5\frac{1}{4}''$ x $6\frac{3}{4}''$) engine of the heavy slow speed type, its normal speed being in the neighborhood of 550 revolutions per minute. The motor is located practically in the middle of the car, projecting upward through the floor to a considerable height, and enclosed by a wooden box. It is rigidly attached to a sub-frame, on which the car body is supported by eight elliptic springs, the sub-frame being carried rigidly on the two axles. Power is transmitted from the motor through a leather faced cone friction clutch, and through a sliding gear transmission, arranged to give four speeds and reverse, to one of the axles. Control levers are provided at either end of the car, by means of which the speed of the motor may be controlled, gear changes made, and also the direction of motion reversed. When the driver leaves one platform to go to the other, the gear levers are locked in a neutral position. Their connections to the gear case then serve as fulcrums for the operating levers and their connections at the other end of the car. The transmission is extremely heavy and the gears somewhat difficult to shift. They are not entirely protected from dust and therefore subject to rapid wear. The cone clutch requires considerable attention to secure smooth operation. If neglected, it takes hold with such brusqueness that jerking of the car results, to the extreme discomfort of the passengers. One of these cars has been in service on the Arad Csanadar Railway but has been practically abandoned because of the clutch and gear troubles.

ENGLISH DAIMLER CAR

58 Several years ago the Daimler Motor Company, of Coventry, England, built a number of small railway cars of the straight gasolene type, equipped with two 30 horse power motors carried on a sub-frame between the axles. They were placed at diagonally opposite corners of the frame, and a sliding gear transmission provided, cen-

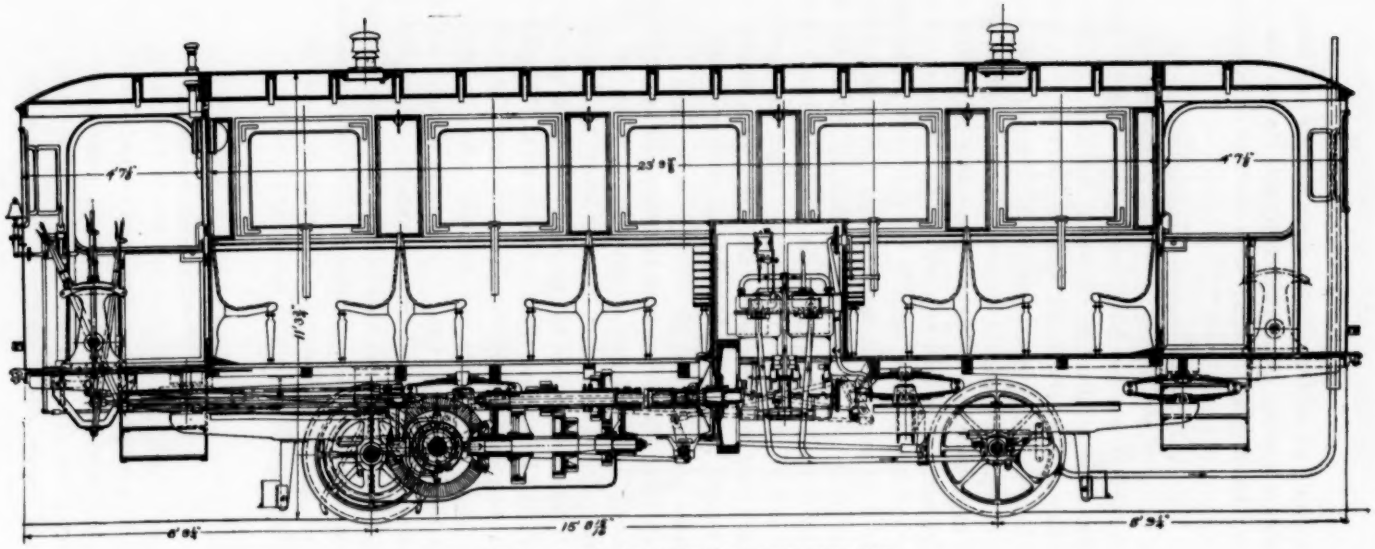


FIG. 7 GERMAN DAIMLER GASOLENE CAR

trally located and so arranged that either or both motors could drive through it, and thence through bevel gearing to the two axles. These cars have not been satisfactory because of clutch and gear troubles, and because they were rather expensive to operate, the fuel cost being high.

59 The usual friction clutches interposed between the motors and transmission permitted the use of either one of the motors independently of the other, a feature which may possess merit in minimizing fuel consumption, and in being able to proceed with one motor if the other for any reason becomes inoperative.

60 Two axle cars, such as the German and English Daimler, are not applicable to all kinds of service because of the long wheel base, which is 15 feet 9 inches in the case of the former, and 15 feet in the latter.

CONCLUSION

61 The author's impressions of the railway motor car situation abroad, gained from personal observation of the leading types herein described in operation, and from personal interviews with railway officials and others more or less directly interested, may be summed up as follows:

62 The field of the railway motor car is very broad indeed. It has always demonstrated its superiority over the ordinary steam train, in making possible more frequent service at lower operating cost, as a feeder to express trains, on branch and main lines, in either very thickly or very sparsely populated districts. It has successfuly competed with electric cars of both trolley and storage battery types, in suburban and interurban service. In the case of the Arad Csanadar Railway, it has replaced steam trains on the entire system except for heavy freight. Further refinement is possible and may be expected, which will extend its field of usefulness.

63 Steam, as a motive power in cars of 80 horse power or over possesses the greatest number of advantages, among which may be named flexibility, reliability and economical operation. First cost is also in favor of the steam car, and likewise to a slight extent maintenance charges.

64 For cars of less than 80 horse power the internal combustion motor shows lower fuel cost than the steam car of like power.

65 Present well known forms of gear transmission with friction clutches which are entirely successful on gasolene automobiles are not suitable for heavy cars because of their inelasticity and the enormous difference in inertia of weights dealt with.

66 Electric transmission possesses the required flexibility and seems best adapted for the purpose.

TABLE 2

BOILER DATA OF PRINCIPAL TYPES OF RAILWAY MOTOR CARS

Name or make	Type	Rated h.p.	Heating surface	Superheat surface	Total	Grate area	Ratio of grate area to total heat surface	Degree of superheat	Steam pressure
Ganz	Vertical-short inclined water tubes	35	91		91	3¼	1 to 25 0		280
Komarek	Vertical-bent water tubes	100	215	32	247	7.0	1 to 35.3	600 F.	210
Great Western	Vertical-vertical fire tubes	250	660		660	11.5	1 to 57.4		160
Taff Vale	Horizontal-horizontal fire tubes	200	465		465	10.0	1 to 46.5		180
Purrey	Vertical-bent water tubes	200	255	80	335	11.6	1 to 29.0	900 F.	284
Lanc. & Yorkshire	Horizontal locomotive type	250	509		509	9.4	1 to 54		180

TABLE 3

COST OF OPERATION OF FOREIGN CARS

Ry. using car	Type	H. p.	weight of train	Operating cost per train mile	Cost of fuel	Wages paid for labor	Remarks	Average running speed
Great Western	Steam	250	Average 55 tons including 1 trailer	0.13	Coal $3 ton	Driver 7s.	20 pounds per train mile	35 m. p. h.
North Eastern	Petrol-electric	85	35 tons	probably 0.15 to 0.16	30c gallon		3½ miles per gal. claimed (9c per mile fuel)	30 m. p. h.
Paris—Orleans	Purrey steam	260	50 tons including 1 trailer	0.08	Coke $6 ton	Driver $1.40	21 pounds coke per mile	35 m. p. h.
Arad Csanadar	Ganz steam	35	About 40 tons including 2 trailers	0.075	Coke $5 ton	Driver about $1.20	9.6 lbs coke per per mile	25 m. p. h.
Arad Csanadar	Gasolene electric	70	About 20 tons	0.073	Gasolene 10c	Driver about $1.20	2.11 pounds gasolene per mile. 2.9 miles per gallon	35 m. h. p.
Arad Csanadar	Gasolene electric	35	About 40 tons including 2 trailer	0.057	Gasolene 10c	Driver about $1.20	1.61 pounds gasolene per mile. 3.75 miles per gallon	20 m. p. h.
Austrian State	Komarek steam	100	50 tons including 2 trailers	0.05	Coal $3.25	Driver about $1.20	15 pounds per mile	25 m. h. p.

Operating costs include, fuel, oil, repairs, and driver's wages.

ANALYSIS OF LOCOMOTIVE TESTS

A. Hirn's Analysis of the Pennsylvania Railroad's Locomotive Test Conducted at St. Louis in 1904

By SIDNEY A. REEVE, WORCESTER, MASS.
Member of the Society

The following analyses were made in an attempt to ascertain what proportions of heat developed within a locomotive boiler were absorbed by the earlier and later portions of the heating surface, or by fire-box and tubes, respectively, or were lost up the stack. The St. Louis tests apparently furnish the best possible basis for such an investigation.

2 These analyses have been applied to the tests of only five out of the eight locomotives reported upon at St. Louis, because by the time that had been done, it had become plain that discrepancies too great to be handled by anyone other than those personally acquainted with the tests were involved. For the same reason, and also because the investigation was begun from mere professional curiosity rather than with any responsible aim in view, the laborious computations have been checked only in spots. The general consistency between the five different series of analyses was relied upon to indicate little probability of error.

3 Further inaccuracy is due to the discrepancy existing in the reports between the chemical analyses of the coal and of the flue gases. The figures given in the following tables for the percentages of surplus air present in the furnace, and for the weight of flue gases passing to the stack per pound of dry coal burned, must be open to question to the extent of about one tenth of their values. None of these inaccuracies applying to individual values, however, seriously affect the conclusions which are enforced by the analyses.

4 The essential boiler dimensions of the five locomotives the tests of which are analyzed below are these:

To be presented at the Indianapolis Meeting (May, 1907) of The American Society of Mechanical Engineers, and to form part of Volume 28 of the Transactions.

Locomotive No. 1499: Pennsylvania simple consolidation (2–8–0).

Grate area	49.2	square feet
Heating-surface: fire box	166.4	square feet
Total	2482	square feet
Ratio of heating surface to grate area	50.5	

Locomotive No. 734: L. S. & M. S. simple (2–8–0).

Grate area	33.8	square feet
Heating surface: fire box	218.9	square feet
Total	2541.2	square feet
Ratio of heating surface to grate area	75.2	

Locomotive No. 585: Michigan Central two cylinder cross compound (2–8–0).

Grate area	49.4	square feet
Heating surface; fire box	165.7	square feet
Total	2819.2	square feet
Ratio of heating surface to grate area	57.1	

Locomotive No. 535: A., T. & S. F. four cylinder balanced (Vauclain) compound (4–4–2).

Grate area	48.4	square feet
Heating surface: fire box	220.3	square feet
Total	2902.0	square feet
Ratio of heating surface to grate area	60.0	

Locomotive No. 3000: N. Y. C. & H. R. four cylinder balanced (Cole) compound (4–4–2).

Grate area	49.9	square feet
Heating surface: fire box	151.7	square feet
Total	3000.0	square feet
Ratio of heating surface to grate area	60.1	

5 The tables and diagrams herewith give the result of the analyses. Each table or diagram presents the variation of the distribution of the heat available from each pound of dry coal burned, to its various possible destinations in the boiler, in terms of a varying rate of combustion and boiler load. The five series of tests agree remarkably in pointing the following apparent results of increasing the draft rate of combustion and boiler load from a moderate to an extreme degree, viz:

a Constancy, or only slight increase, in the heat lost up the stack;

b Constancy, or only slight increase, or possibly a slight decrease, in the heat absorbed by the tubes;

c Marked decrease in the amount of heat getting to the steam otherwise than through the tube surface, or supposedly by radiation through the fire-box walls;

d Marked increase in the heat not accounted for by the test.

6 The only heat destination not computable from the data supplied in the reports is the external radiation. This, from the nature of an internally fired well lagged boiler operated under constant steam pressure, is naturally (*a*) very slight and (*b*) constant for all boiler loads. Reduced to the terms of the diagrams or per one pound of

TABLE 1 LOCOMOTIVE No. 1499

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	H at apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
110	22.7	73.5	19.10	373	78.9	50.7	16.1	2.0
111	27.8	58.8	17.56	445	77.5	50.5	15.4	6.0
109	42.6	56.8	16.55	533	62.9	27.7	14.6	16.0
103	42.4	51.1	16.64	596	67.2	37.0	13.3	12.4
112	56.2	37.1	15.53	662	55.9	27.5	15.2	16.5
102	66.5	44.3	15.40	707	53.4	15.6	16.0	23.1
105	77.8	52.6	17.15	797	47.0	28.0	17.3	25.2
116	71.5	32.8	14.01	807	55.5	30.0	15.8	12.0
118	70.1	30.2	14.30	815	53.1	28.0	14.0	15.4
101	86.4	38.6	15.79	817	45.3	11.6	17.2	22.0
115	82.1	21.0	13.41	867	50.6	21.5	14.8	15.6
117	84.6	69.2	18.68	891	48.7	15.6	20.0	16.0

coal burned, therefore, it should stand as a small quantity decreasing in proportion as the rate of combustion increases. It must fail completely, therefore, as an explanation of the increasing proportion of heat unaccounted for by the test under the heavier boiler loads.

7 The results shown are so surprising as to be, to the writer, incredible. In Locomotive No. 1499 the load is varied by 239 per cent and the rate of combustion by 372 per cent. In consequence, the efficiency drops from 78.9 to 48.7. Why does it do this? Where does the lost heat go? One would naturally reply, "Up the stack, because under heavy load there is no longer sufficient heating surface to absorb it." But the observed smoke box temperatures show

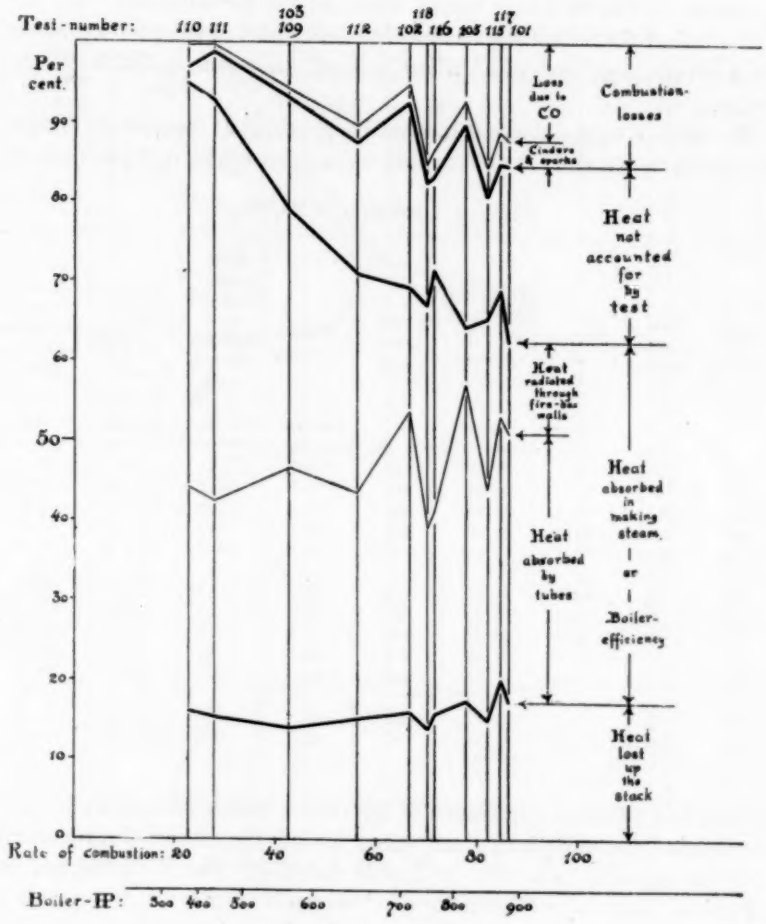


FIG. 1 LOCOMOTIVE No. 1499

almost no increase in the loss in this direction. This fact has already been pointed to as an indication of how efficient the locomotive boiler is under forcing. But if so, where is the efficiency? The locomotive engine has long been pointed out as a remarkably efficient power plant. How far this contention may be supported on the engine side of the question by the St. Louis tests I have not yet investigated; but it is certain that they show the locomotive boiler part of the power plant to be a pretty poor sort of an affair, except when run under very light loads.

8 In stating the above it has not been said that locomotive designers are to be blamed for not turning out a more efficient type of boiler.

TABLE 2 LOCOMOTIVE No. 734

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box walls	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
201	32.8	70.1	21.32	322	65.2	17.1	15.6	16.0
202	41.8	64.7	20.51	439	71.3	23.1	15.5	8.6
205	52.7	69.5	21.12	489	61.4	11.6	17.5	14.9
203	60.0	52.4	19.00	539	58.6	14.2	14.7	19.2
206	80.8	35.3	17.19	683	56.3	18.4	15.1	20.0
209	101.7	43.2	18.25	776	50.3	10.15	16.5	24.4
220	117.0	33.7	17.41	820	45.5	−1.6	15.9	31.1
219	120.8	36.5	18.32	832	45.0	−1.7	17.1	30.1
210	121.3	51.2	21.30	832	45.6	−9.2	20.3	24.8
208	123.0	34.2	17.65	854	46.2	2.3	16.7	29.3
213	133.4	34.7	17.75	861	42.6	−2.6	17.3	31.4
212	139.0	30.6	17.56	887	41.7	−0.9	16.8	33.8

Under the peculiar conditions of operation which prevail with locomotive boilers, and particularly when forced, the efficiencies recorded may be regarded as a very creditable showing. But it should not be disguised that the performance of a locomotive boiler when forced is a heavy discount from what the same boiler does when steaming slowly.

These discounts in efficiency are shown in Table 6.

9 My personal belief is that these efficiency figures are correct, and that the heat is lost up the stack to a greater degree when the boiler is forced than when steaming easily. Indeed, I believe that the stack loss is the chief explanation of the decreasing efficiency under forcing. My reasons for this position are:

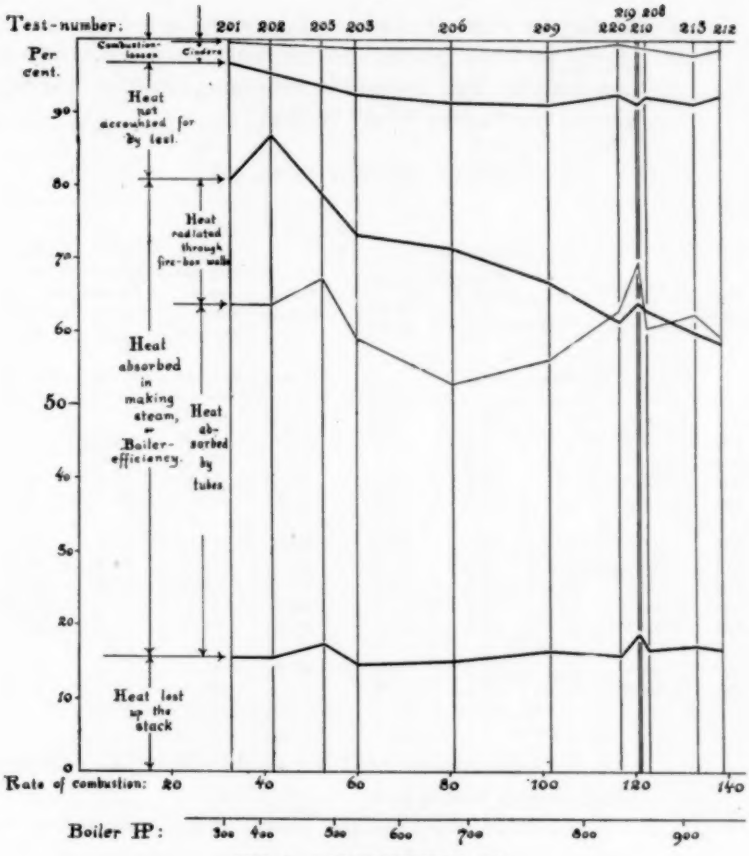


FIG. 2 LOCOMOTIVE No. 734

a It is what is naturally to be expected;

b My little faith in the pyrometer as an instrument of precision, particularly when temperatures rise to the point where radiation begins to be as active as conduction;

c The unquestionably greater accuracy of the instruments relied upon for determining the other heat quantities recorded;

d The way in which this assumption solves this entire riddle. For if the stack loss of the diagrams be imagined as increasing with the load, instead of remaining constant, the incidental conclusions would be that

TABLE 3 LOCOMOTIVE No. 585

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
301	20.8	97.5	20.7	324	70.4	43.7	14.1	10.3
302	20.5	99.5	22.3	346	76.9	42.4	15.0	2.9
303	21.7	105.5	22.4	373	78.4	43.7	15.9	2.7
306	34.0	41.1	15.8	527	70.4	56.2	11.4	11.5
305	35.8	48.1	16.4	586	74.1	60.7	13.1	9.0
308	42.2	45.3	16.3	651	69.0	49.8	13.0	13.4
317	49.4	91.3	21.2	711	64.6	25.4	18.4	9.3
312	54.4	65.5	16.8	727	60.3	32.3	15.0	18.2
309	51.8	50.3	17.1	739	64.2	43.5	14.2	16.5
318	55.4	49.1	16.9	779	63.2	37.0	15.3	12.4
319	53.4	59.3	17.8	793	67.4	48.4	15.8	11.2
313	56.0	53.8	17.1	799	64.3	49.4	14.1	17.2

1 the heat unaccounted for would remain a small constant for all loads, and

2 the heat reaching the steam from each pound of coal would be divided between a decreasing proportion coming through the fire box walls (for the gross fire box radiation must be fairly constant for all loads above an insignificant one) and an increasing proportion coming through the tubes, the further ends of which are well heated only under a high rate of combustion.

Neverthless, the man who has only the printed records to go by may not be too didactic in his conclusions. Having pointed out the facts,

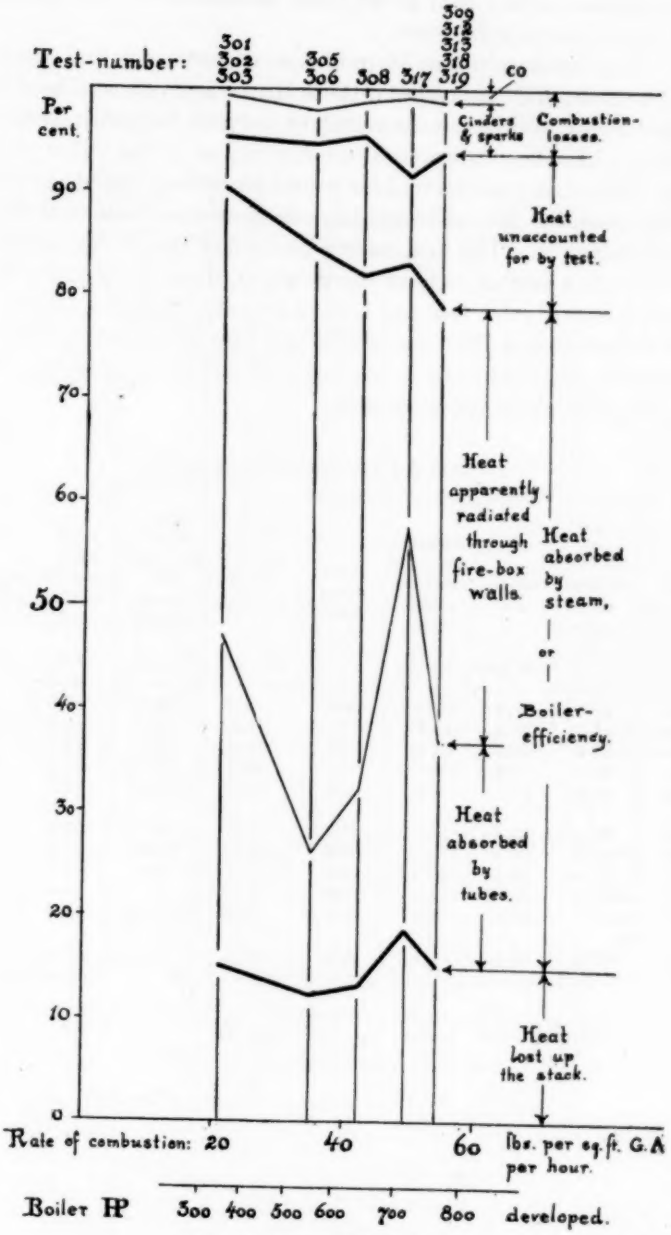


FIG. 3 LOCOMOTIVE No. 585

the explanation may well await their discussion by the gentlemen who were engaged in the work.

10 One conclusion may be published dogmatically and emphatically, however; and that is that if these Hirn's analyses had been made at the time of working up the results of the tests for publication, there would not have been the present uncertainty as to the value of these tests. The heat unaccounted for would have been noted, and those familiar with the ground would have been able to chase and capture the discrepancy. The engineering profession should lay down the rigid law, as a matter of mere labor saving, time saving and value of result, that no boiler test has been acceptably reported until it has been subjected to a Hirn's analysis, and that no engine test has been acceptably reported until it has been subjected to an entropy-temperature analysis to the same end.

TABLE 4 LOCOMOTIVE No. 535

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
601	18.1	91.4	21.3	309	78.4	44.4	15.0	3.6
602	24.2	73.3	19.5	377	71.1	34.6	14.5	11.5
603	28.5	68.3	18.8	453	73.6	35.3	14.7	9.1
604	42.6	76.6	19.9	600	64.5	21.6	16.3	15.3
605	42.5	78.6	19.6	612	66.2	25.7	16.4	14.7
606	51.0	59.4	17.9	721	65.0	28.1	15.5	17.1
607	67.4	58.0	17.6	896	62.4	22.9	16.5	18.1
609	92.0	62.1	18.5	1005	50.1	11.0	17.5	25.1
613	105.5	39.8	16.3	1086	47.3	6.7	16.2	28.7
160	120.6	39.6	15.9	1146	44.0	7.9	16.2	30.2
611	117.9	62.5	18.4	1187	46.1	1.9	19.0	27.6

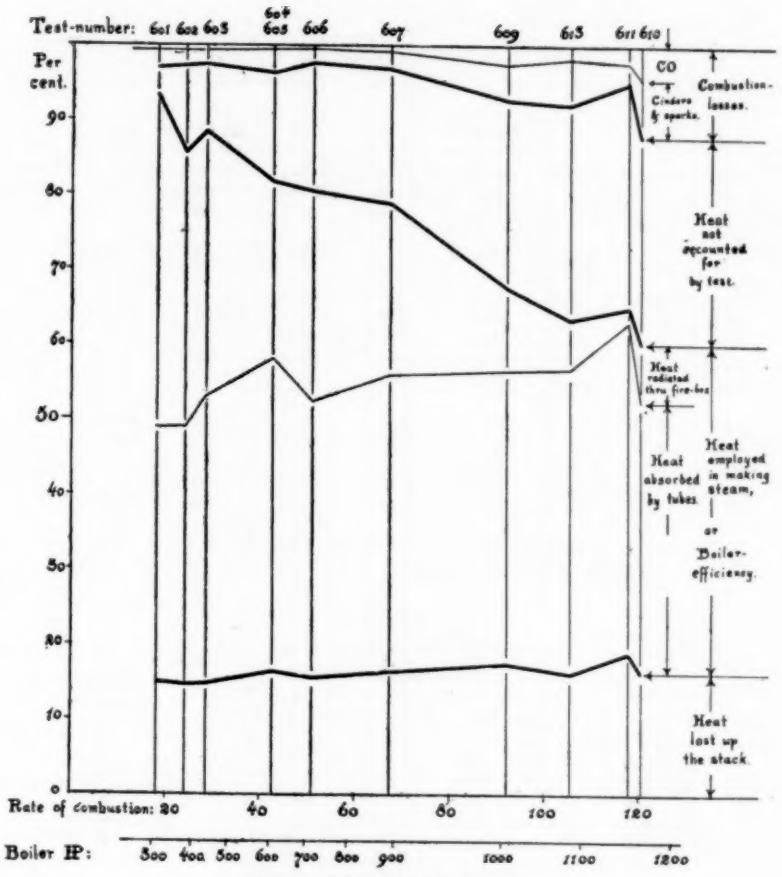


FIG. 4 LOCOMOTIVE No. 535

TABLE 5 LOCOMOTIVE No. 3000

Test number	Rate of combustion	Surplus air	Weight of flue gases per 1 lb. of dry coal	Boiler horse power	Boiler efficiency	Heat apparently radiated through fire box	Heat apparently lost up the stack	Heat not accounted for by the test
		Per cent	Pounds		Per cent	Per cent	Per cent	Per cent
801	25.8	70.0	19.0	436	75.3	33.7	14.2	8(?)
802	35.0	66.0	18.6	542	69.0	26.4	14.6	13(?)
805	47.2	67.5	18.9	697	65.3	16.3	16.5	15.5
809	60.6	53.9	17.5	868	63.9	25.9	16.5	17.0
806	62.4	48.9	16.9	903	64.1	25.0	16.2	15.0
813	69.6	44.9	16.3	958	61.7	26.4	15.6	19.2
814	77.9	62.5	18.5	1093	62.1	14.5	18.8	14.4
815	98.8	49.8	16.8	1130	51.0	9.9	17.3	27.4
807	116.2	46.0	16.5	1156	53.0	14.1	16.8	27.3
811	116.2	54.6	17.4	1297	49.8	4.3	19.2	27.6
812	134.2	40.4	16.1	1421	46.9	5.1	18.3	32.5

TABLE 6

Locomotive	Percentage increase in		Discount from best efficiency
	Rate of combustion	Boiler power	
No. 1499	372	239	42.6
No. 734	424	275	40.2
No. 585	269	247	23.1
No. 533	652	384	43.99
No. 3000	520	326	37.7

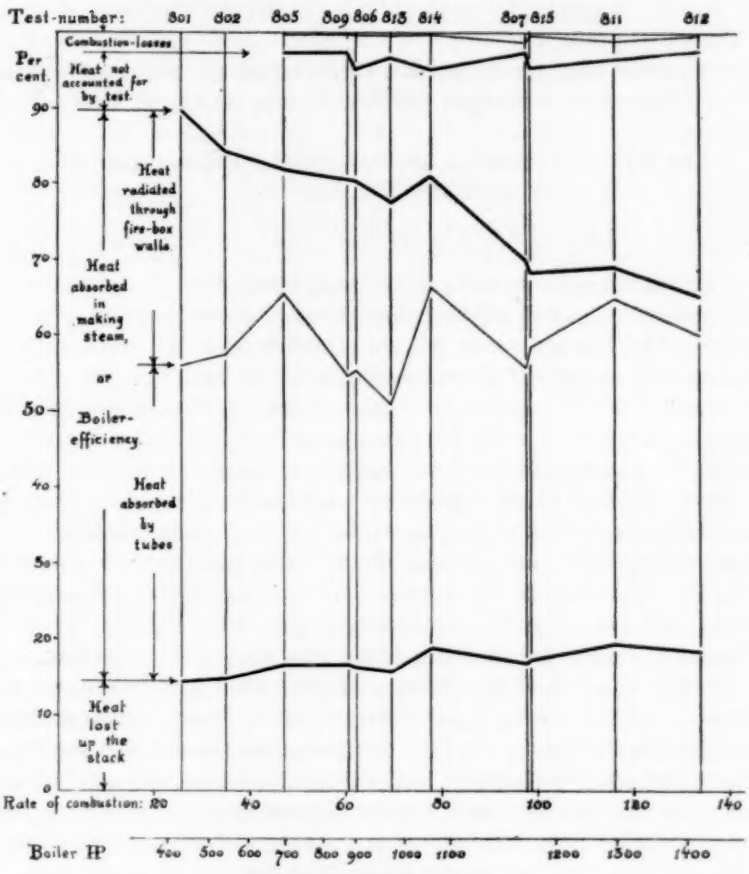


FIG. 5 LOCOMOTIVE No. 3000

THE ORDNANCE DEPARTMENT AS AN ENGINEERING ORGANIZATION

AN ADDRESS DELIVERED AT THE DEDICATION OF THE ENGINEERING SOCIETIES BUILDING IN NEW YORK, APRIL 18, 1907

BY WILLIAM CROZIER, BRIGADIER-GENERAL, CHIEF OF ORDNANCE, U. S. A.

GENTLEMEN OF THE SOCIETY OF MECHANICAL ENGINEERS:

I would remind you of Noah Webster's definition of engineering as the science and art of utilizing the forces and materials of nature. It is probable that not many who are familiar with the science which enters into the subject of engineering make claim to the title of engineer which is not justified, by reason of their unfamiliarity with the practice of the art. I think it can be said that there is no disposition to dispute the right of those who have investigated deeply the natural sciences, without which engineering would be merely a rule of thumb process, to take rank as engineers; but at what stage it is to be conceded that those who practice the art, commencing with the mechanics, advancing to the foremen, considering also the superintendents, and even scrutinizing somewhat the administrators, are to be granted the right to call themselves engineers is not quite clear.

2 The creations of the Ordnance Department with which you are all more or less familiar, either through inspection or through description and illustration in the daily and periodical press, attest the practice of the art of engineering construction, and men who are familiar with the methods by which results of magnitude are accomplished, know well that powerful engines, and strong and ponderous but delicate machines are not produced without the initial application of science of a high order. There is, however, little opportunity or temptation for those who are engaged in civil occupations, even for those whose profession it is to produce structures akin to the works of ordnance constructors, to critically examine and analyze the mechanisms which are manufactured for purposes of defense, and to form an estimate of the degree of scientific as well as of mechanical skill which is brought to bear in their production. This building in

which we are gathered this evening, generous product of a noble impulse, is an inspiration to anyone whose duty it is to deal with the forces and materials of nature; and in an effort to show you that the officers of the army, who produce the weapons with which we wage our happily infrequent wars, follow the processes of thought and computation and design which precede construction, involving a knowledge of basic principles and the deduction of methods therefrom, in such manner and to such degree as to justify a claim to scientific knowledge and employment, and to demonstrate their worthiness to be classed with you as engineers, I will explain to-night briefly, and by way of illustration merely, a little of the scientific process by which ordnance material is designed.

3 In thinking of the subject of weapons the first which naturally comes to mind is the gun, which, whether large or small, is the principal weapon with which armies or fortifications are armed today. Although there is plenty of science in the design of small arms, I will leave them and arrest your attention upon certain points in the design of guns of the larger size. I will not go much into theory in relation to gun construction, because a little later I am going to ask you to follow me somewhat more closely through some theoretical considerations accompanying another class of construction; and the most of what I shall say in regard to the theories upon which our designs are based is not new, and is found in the text books on ordnance construction; but perhaps I may be able to point out certain applications and consequences which have not been generally realized, or set forth in publications.

4 A thick cylinder, built to withstand the highest possible interior pressure which is one of the objects to be attained in the construction of the cannon, is not of frequent application in the arts; and therefore civilian mechanical engineers have not had much occasion to study its attributes, methods of construction, and limitations. It is well known to engineers, however, that when such a cylinder is subjected to an interior pressure the concentric layers of metal near the bore are subjected to much greater tension than those near the outer periphery of the cylinder; the relative tensions to which the layers are subjected, or rather the circumferential extension of these layers, since both the circumferential or tangential tension and the pressure in the direction of the radius contribute to this effect—are shown by the curve in the figure on the following page.

5 The thickness of this cylinder is equal to the diameter of the bore, which can be shown to be that beyond which it is not useful to increase it, because of the slight gain in strength which would result. As the

curve of extensions is drawn to scale, the interior ordinate representing the elastic limit in extension of the material of which the cylinder is formed, it is seen at once how very unequally the different concentric layers are extended; the outer one experiencing less than one-third of the strain which is brought upon the layer at the bore. The resistance of the cylinder can be represented by the product of its thickness multiplied by the mean extension, as taken from the curves, which is an expression equivalent to that for the area of the surface

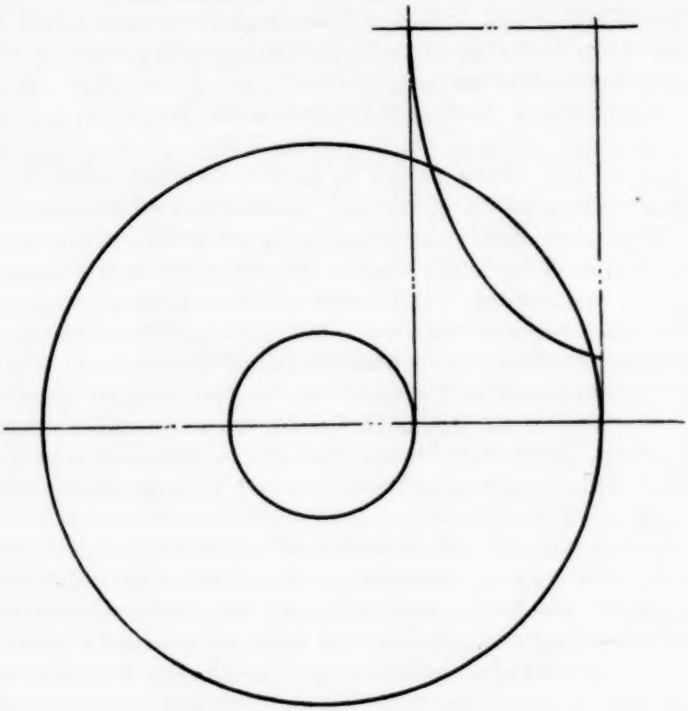


FIG. 1

included between the curve, the ordinates corresponding to the inner and outer radii of the cylinder and the axis from which the ordinates of the curves are set off. If we could manage so that all the concentric layers of the cylinder should be equally extended by the interior pressure, the curve would become a straight line drawn through its upper point, and the resistance of the cylinder would be measured by the rectangular area lying under this straight line. The loss of efficiency, due to the inequality of the strain, is represented by the

large triangular area lying between this straight line and the curve. It is the province of the designer of ordnance so to utilize his material as to diminish this area. You all know the process used, which is to form the gun of concentric layers shrunk one upon another, so that the finished gun shall have the layers of the inner cylinders, near the bore, compressed tangentially, while those of the outer ones are correspondingly extended. The interior pressure can then attain some magnitude before the metal of the bore is brought to a neutral state,

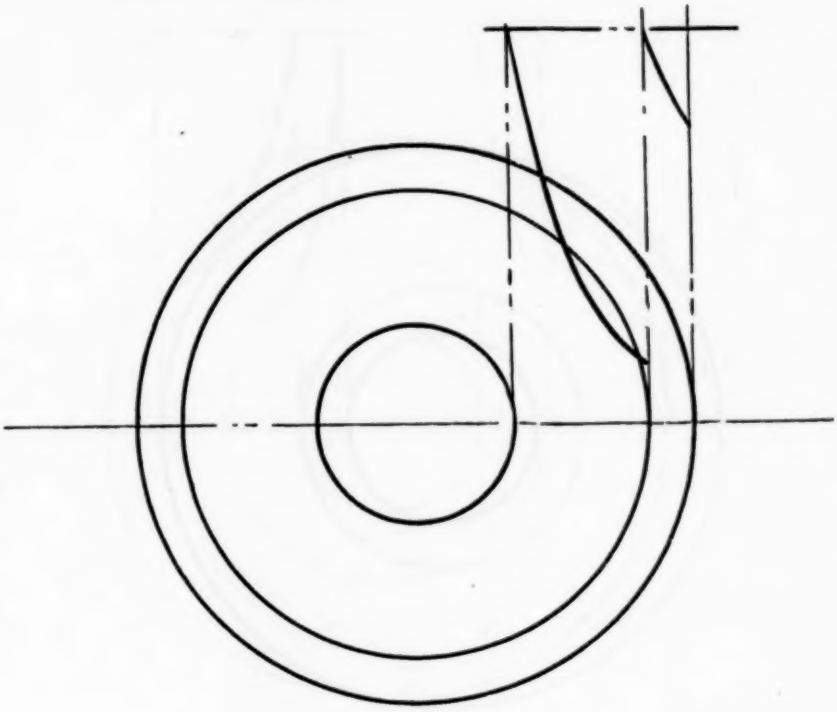


FIG. 2

and there can be added to this pressure as much as the entire pressure in the case of the simple cylinder, before the metal of the bore is brought to a state of elastic extension up to its limit; and this without overstraining any of the outer layers if the gun is properly constructed.

6 This explanation is very plain and very easily understood. It does not pass the comprehension of the foreman, or the layman; and an appreciation of its justness and a recognition of the necessity of its application does not constitute a sufficiently high order of mental

achievement to justify the title of engineer as accompanying its mastery. The real engineering process comes in the quantitative analysis which determines the amount of the shrinkage, or the difference in diameters of the cylinders which are shrunk upon each other, in order to get the best effect from the material, and the magnitude of the pressure which the finished cylinder is capable of supporting. This analysis involves a knowledge of the materials, and an intelligent use of the science of mathematics, which is the soul of the engineer's profession, and without knowledge of the application of which it seems

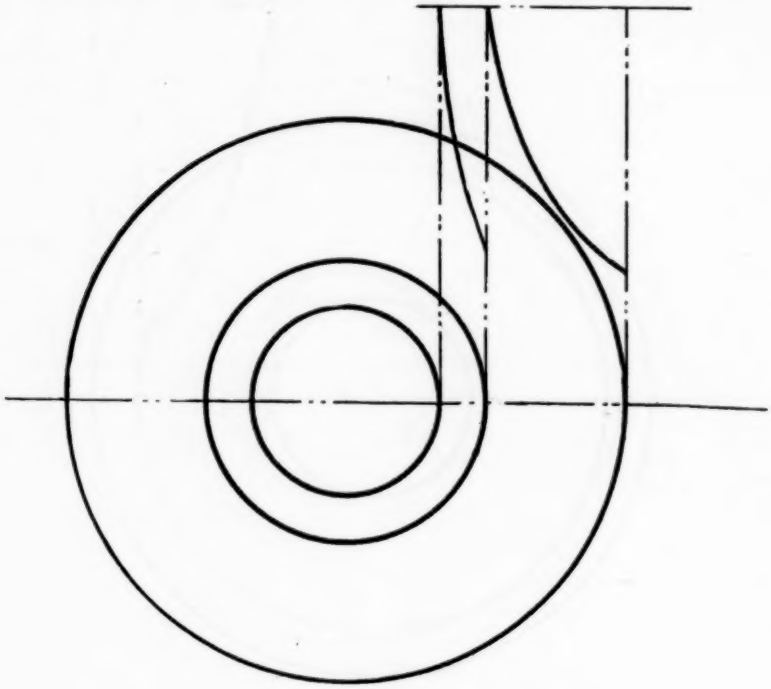


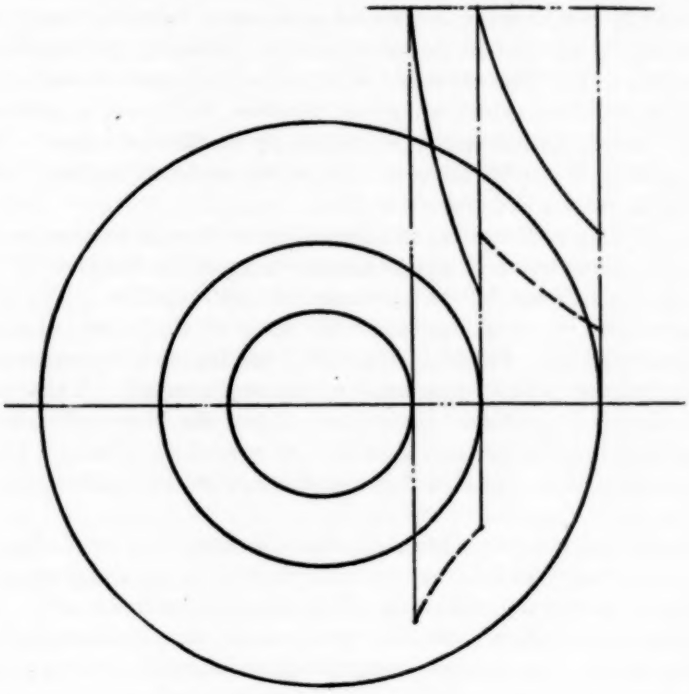
FIG. 3

to me that he can not lay full claim to the title. I will content myself here with a qualitative analysis only, and will not go into the mathematics of the subject for the reason that, although I believe you would be interested therein if you had the time necessary to devote to the subject, I intend to be a little more mathematical later on with reference to another computation, as I have said.

7 The extensions in the layers of two concentric cylinders shrunk one upon another, are shown by the two curves in Fig. 2 and it is

easily seen that if the shrinkage be properly adjusted, the metal at the interior surface of both cylinders will be brought to its elastic limit of extension at the same time. Inspection is sufficient to show that the mean ordinate of these two curves is greater than that of the curve corresponding to the simple cylinder previously spoken of; and it is also quite apparent that the total area above the curves is less.

8 In addition to the adjustment of the amount of shrinkage in order to secure the best result from our compound cylinder, there is also that of the length of the radius of the circle of contact of the two



FIO. 4

cylinders. In the compound cylinder shown the outer tube is too thin, and there is, therefore, too small a departure from the curve of extensions of the simple cylinder. In the next compound cylinder the inner tube is too thin and, therefore, the thick outer cylinder shows a very close similarity to the disadvantageous curve of the simple cylinder. An application of the methods by which maximum and minimum states of a function are determined would show that the most advantageous result is obtained when the radius of contact is a mean

proportional between the radius of the bore and that of the outer circle of the compound cylinder. In this case the curve of extensions of each cylinder is shown in Fig. 4 which corresponds to the best result which can be gotten from a compound cylinder of two layers.

9 In this figure there is also shown the state after the completion of the shrinkage, and before the interior pressure is applied. The dotted curve below the axis represents the compressions of the layers of the inner cylinder, while the other dotted curve shows the corresponding extensions of the outer one.

10 Now having gotten the best result obtainable in the compound cylinder of two layers, the question arises as to how this result may be improved upon; and the answer is by increasing the number of cylinders, so that the curves of extension of the layers of each, lying between ordinates which are closer together, will have no points as low as the inferior extremities of the two curves which are shown; thus again raising the mean tension of the curves and still further, diminishing the total area lying above them.

11 And again the question arises whether there is any end to this process, other than a practical limitation as to the thickness of the cylinders which can be machined and shrunk together. The limit is arrived at by consideration of the state of the inner tube in a finished cylinder. We see by the dotted line the state of compression of this cylinder with two layers, properly proportioned. If the number of layers be increased the compression of the inner cylinder will be increased, and after a while we will arrive at the elastic limit under compression of the metal of this cylinder, beyond which we must not push it.

12 A computation would show that this result can be reached by the employment of four concentric cylinders, of material equal in quality to that of the inner tube. The compound cylinder could then be safely subjected to a pressure which would carry the metal of the bore through the range from compression to its elastic limit to extension to its elastic limit, and if these two limits were equal the range would be double either of them; and we see that by the process of building up under shrinkage we would have doubled the strength of our compound cylinder over that of the simple cylinder of the same thickness. Since we must not compress the inner cylinder beyond its elastic limit, it is evident that we can not go any further than this either by an increase in strength or by a multiplication in number of the outer cylinders, unless we are to make these cylinders of more rigid material, that is, of material having a greater modulus of elasticity than that of the inner tube, which we have not thus far been

able to find. There follows a result which has not been very prominently brought to attention, namely, that a gun formed by wrapping a tube with wire can not be made of any greater theoretical strength than one of as many as four concentric cylinders, notwithstanding the greater strength and the multiplicity of layers of the wire envelope.

13 A practical advantage is had in that, in such a cylinder, there is a greater reserve of strength beyond the elastic limit of the tube and, therefore, we are justified in using a smaller factor of safety and working the compound wire cylinder more nearly the limit of its theoretical strength. There may be also an advantage of cheapness of construction, since wire of great strength can be manufactured at much less cost than the large forgings which are used in gun construction.

14 For an exposition, in its earlier stages, of the theory upon which the gun is constructed, we are indebted to Lamé, the French scientist who, in his "Lessons on Elasticity," gave an early analysis of the strains to which the elements of a hollow cylinder are subjected. His work was followed and amplified by Gadolin in Russia, by General Virgile of the French service, and by Colonel Clavario of the Italian army; while the latest refinement in the formulae as we use them now was made by Colonel Birnie of the United States Ordnance Department. General Rodman, whose name is one of the greatest in the history of ordnance, made use of the principle of initial compression of the metal of the bore, which he accomplished by cooling from the interior the large castings from which his guns were made, which process was replaced by the more exact one of shrinkage when forged steel cylinders of limited thickness and much higher physical qualities replaced the masses of cast iron of which the Rodman guns consisted.

15 An example of the blundering application of a good principle, as when an attempt is made without the clear guidance of theory to practice an art which should be founded upon science, is seen in the Parrott guns of our civil war time, which were formed by shrinking a band of wrought iron over the breech portion of a cast-iron body. The principle was good, and the strength of the guns should thereby have been increased; but because of the lack of application of mathematical analysis to the determination of the proper amount of shrink- which should have been used, the operation was grossly overdone, and the guns by many failures, suffered in reputation and discredited a good principle.

16 I will now leave the subject of guns and pass to one which is even less frequently bought to the attention of those who do not have to concern themselves with ordnance construction. I refer to the

carriages upon which the guns are mounted and maneuvered; and with reference to these I will ask you to consider by way of a typical illustration, the method by which the recoil of the gun is controlled; since this process is one which is even more unfamiliar in the commercial practice of mechanical engineering than is the use of the thick cylinder. A 12-inch gun in its recoil has an energy of practically 1000 foot tons, and to absorb this in the short distance of three feet without shock and without undue strain upon any part of the structure, which must endure many repetitions of it, is a necessity which I do not understand as arising in any other class of construction.

17 Fig. 5 shows the general method by which this is accomplished. A piston is attached to the recoiling gun and is drawn through a cylinder filled with liquid, generally oil; the resistance which checks the recoil is produced by forcing the oil from one side of the piston to the other through small orifices. As the velocity of recoil of the gun

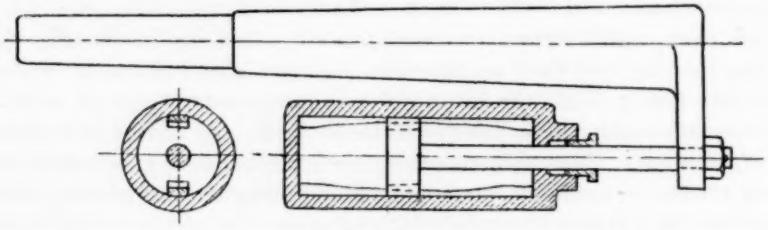


FIG. 5

in its earlier stages is higher than when it is nearly brought to rest, orifices of constant size would produce a much greater resistance in the earlier portions of the recoil than in the later, and would result in a much higher strain than the mean on the piston rod, and on the cylinder and its attachments, all of which would have to be made strong enough to withstand the highest strain. It can be shown that in such a cylinder, which was the kind at first used for the purpose of checking recoil, the maximum strain is more than four times the mean. In order to reduce the strain to the mean it is necessary to vary the area of the orfices as the recoil proceeds, and one of the methods of accomplishing this is to form the orifices by cutting in the piston slots which slide over bars bolted along elements of the cylinder; the orifices are the portions of the slots which are not filled by the bars, and as the latter are of constant width and varying depth, the size of the orifices can be varied in accordance with any desired law.

18 The computation of the curved surfaces of the bars, whose character is desired to be such that the orifices shall be diminished at a rate proper to produce constancy of pressure in the cylinder, is that to which I now invite your attention; and in describing it with sufficient clearness to be understood I will make use of certain mathematical expressions for which I would feel compelled to apologize to an audience of any other class. But the expressions will be simple, and will be easily recognized even by those whose early success has led them away from the direct application of this handmaid of the engineer into directive positions, in which their differentiations and integrations are done for them by others. I hope I shall be able to indicate a much more extensive application of mathematics and theoretical mechanics than that which I am about to show directly.

19 The problem would be much easier if the gun should start in recoil with its maximum velocity at the beginning of its motion; the subject of its control could then be handled by very little variation from the methods of analytical mechanics, as ordinarily applied. But this is not the case; as soon as the gases produced by the burning of the powder charge attain sufficient pressure to overcome the mere passive resistance, such as friction and the resistance to distortion of the band of the projectile, the gun commences to recoil, and the velocity increases until the diminishing pressure falls below these passive resistances. If the gun were free to recoil, without any kind of restraint, it would commence to do so as soon as the projectile began to move, and its velocity would increase as long as the powder gases exerted any pressure upon it, after which it would continue indefinitely at the same rate of motion.

20 There has thus far been deduced no mathematical expression for the variation of the velocity of recoil of the gun during this early period of its motion, to meet which the orifices for the flow of the oil from one side of the piston to the other in the recoil brake cylinder must increase in size; therefore we attack the subject semi-graphically as follows:

21 We assume the distance in which we wish to check the recoil, and this leaves us with two elements to compute, first, the magnitude of the constant resistance which the brake must offer in order to check the gun in the assumed distance; and second, the size of the orifices for the flow of the oil at each point of the passage of the piston through the cylinder, necessary to produce this resistance. The computations relating to the gun, the powder charge, and the projectile give us an expression for the velocity of the latter at each point of its travel through the bore, and this velocity is plotted as the ordinate of the

curve shown in Fig. 6, of which the abscissa is the distance from the starting point of the projectile, measured along the bore. This curve we will take for our starting line.

22 The mathematical expression for the ordinate of this curve is $\frac{dx}{dt}$; if we plot another curve, as shown in the same figure, whose ordinates shall be the reciprocals of those of the velocity curve, the mathematical expression for these ordinates will be $\frac{dt}{dx}$; the expression for the differential of the area under the second curve is $\frac{dt}{dx}\,dx$; that is, the ordinate into the differential of the abscissa; and the area under the curve is the integral of this expression, that is, the integral of $\frac{dt}{dx}\,dx$, which is the integral of dt, or t. That is, the area under the second curve measured out to any ordinate is the time which it takes the projectile to reach the corresponding point of the bore.

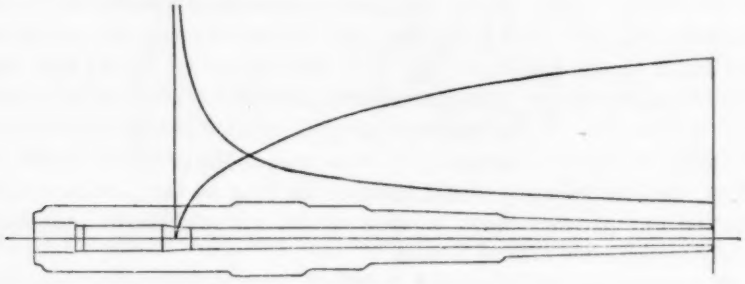


FIG. 6

23 By combining these two curves, and plotting a third one whose abscissae shall be the ordinates of the time curve, and whose ordinates shall be the corresponding ones of the velocity curve, we obtain the curve shown in Fig. 7, which is that of the velocity of the projectile as a function of its time of travel. This curve has a point of inflection corresponding to the maximum powder pressure, when the acceleration of the shot is naturally the greatest.

24 Since the projectile is moved in one direction and the gun is moved in the opposite by the pressure of the powder gases, the velocities of motion of the two would be inversely proportional to their weights, were it not for the fact that the powder charge itself has considerable weight which must also be moved by its own pressure; therefore, we have it that the weight of the gun multiplied by the

velocity of the recoil is equal to the weight of the shot multiplied by its velocity, plus the weight of the powder multiplied by the velocity which it has, or the formula:

$$W_g V_g = w_s v_s + w_p v_p$$

25 The best theory which we can form as to the distribution of the powder gases behind the shot, while the latter is moving along the bore, is that they remain at all times evenly distributed between the projectile and the bottom of the bore. Under this supposition the center of gravity of the powder charge is always half way between the base of the shot and the bottom of the bore, which would involve a velocity for this center of gravity just one-half that of the shot; we can, therefore, substitute for the velocity of the powder charge in the

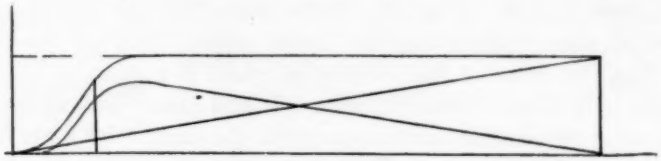


FIG. 7

formula one-half of the velocity of the shot, which makes the formula the following:

$$W_g V_g = w_s v_s + w_p \frac{v_s}{2}$$

Solving this formula we have:

$$V_g = \frac{(w_s + \frac{1}{2} w_p)}{W_g} v_s$$

26 Since the coefficient of the velocity of the shot is a constant quantity, the velocity of recoil of the gun is directly proportional to it, and we can consider the same curve as representing the velocity of recoil of the gun as a function of the time, by bearing in mind that the scale is different. This gives us the velocity of recoil during the period in which the shot is in the bore of the gun; but the formula does not hold good after the shot leaves the bore, for the reason that, freed from restraint of the projectile, the powder gases then rush from the bore with greatly increased velocity, much greater than one-half that of the projectile, and greater also than that of the projectile itself.

27 The gases, however, still exert an appreciable pressure upon the gun, and continue for a time to accelerate its motion. We have

means of measuring the maximum velocity of the gun, upon recoiling freely, and also of measuring the maximum velocity of the projecti'e by substituting these measured velocities in the first formula given, we have one in which the only unknown quantity is the maximum velocity of expulsion of the powder charge, which can therefore be deduced. For guns of similar class this figure should be approximately the same, and having tried the experiment for one gun of a class we can use the same figure in computations relating to other guns. The result of such experiments indicates that the mean of the maximum velocity with which each portion of the charge of smokeless powder is expelled from the gun is about 4700 feet per second; and substituting this figure, together with the maximum velocity of the projectile, in the first formula we get the maximum velocity of recoil of the gun, supposing always that it should recoil without retardation. By drawing parallel to the axis of time a straight line at a distance from it corresponding to the maximum velocity thus obtained, we know that the curve of the velocity of recoil as a function of time must rise to this line, become tangent to it, and continue along the line indefinitely; we are thus able to complete the curve with a very fair approximation to accuracy. The point of tangency is hard to determine; but we can remember that the exact instant at which the last breath of the powder pressure ceases to accelerate the recoil in the slightest degree is not very important.

28 Suppose now we have a constant force to retard the recoil of the gun. Such a force would diminish the velocity of recoil proportionally to its time of action, and the loss of velocity would be represented by the ordinate of a straight line such as we have drawn in the figure. By prolonging this line until it reaches the curve of the velocity of recoil, and dropping the corresponding ordinate to the axis of time, we obtain the time which would be required by such a retarding force to completely stop the gun. Subtracting from each ordinate of the curve of velocity of free recoil the corresponding ordinate of the straight line, we can plot a new curve which shall represent the velocity of recoil of the gun under the action of the brake.

29 Remembering that the curve gives this velocity as a function of the time, the expression for it is $\frac{dx}{dt}dt$; the differential of the area under the curve is $\frac{dx}{dt}dt$; and the area itself is the integral of this expression; thus we have $\int \frac{dx}{dt}\,dt = \int dx = x$. Therefore, the total area

under this last curve is the total length of recoil. From the manner in which the ordinates of the last curve are obtained, each one of them is equal to that portion of the corresponding ordinate of the free recoil curve which lies above the straight line; and this being true of every ordinate it follows that the total area between the inclined straight line and the free recoil curve is equal to the area under the last curve. That is to say, if we draw this straight line so as to include between it and the curve of velocity of free recoil an area equal to the assumed distance in which we wish to stop the recoil of the gun, this line will give us the total time which would be required to check the recoil, and the maximum velocity of the recoil divided by this total time would give the negative acceleration of the recoil, or the retardation of the gun. The mass of the gun multiplied by this negative acceleration is therefore equal to the retarding force; which is the first of the elements that we were seeking. The method of drawing the straight line so as to cut off between it and the curve the area equaling the assumed length of the recoil involves measuring, with

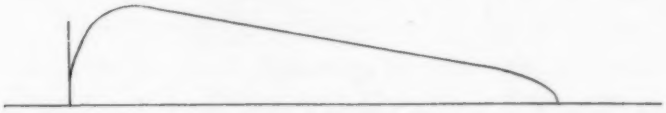


FIG. 8

a planimeter or otherwise, the area under the portion of this curve which is really a curve; with this area measured the process is a simple one.

30 Having the total resistance which the brake must offer in order to check the gun in our assumed distance, we must also have, in order to properly proportion the orifices, the velocity of recoil of the gun, which is that of the motion of the piston through the cylinder, at each point of the recoil, as well as at each instant thereof; that is, we must have the velocity of recoil as a function of the distance recoiled. From the last curve drawn we are able, as just explained, to obtain this; for, by measuring the area under this last curve out to any ordinate we obtain the distance recoiled in the time corresponding to the ordinate. By plotting this distance as the abscissa and the corresponding velocity as the ordinate, we obtain a new curve of the velocity of recoil as a function of the distance, which is shown in Fig. 8.

31 The next step involves a formula with which you are all familiar; $v^2 = 2gh$, in which v is the velocity of flow of the liquid through

the orifice in the lower part of a containing reservoir, and h is the height of the upper surface of the liquid above the orifice. If Δ is the weight of a cubic unit of the liquid, the pressure per square unit at the height of the orifice is equal to $h\Delta$, which gives us $h\Delta = p$. p is equal to the total pressure, or resistance, of the brake divided by the area of the brake piston; representing this area by A, and substituting the value of h in the formula for v, solving it we get

$$v = \sqrt{\frac{2\,g\,B}{\Delta\,A}}$$

As all the terms here are known we get the value of v; that is, the velocity at which the liquid must be forced through the orifices in the piston, in order to produce the constant resistance which has been determined.

32 Since all the liquid which is displaced by the piston in its motion through the cylinder must pass through the orifices to the other side, the velocity of the piston multiplied by its area must equal the velocity of the flow of the liquid through the orifice, multiplied by the area of the orifice, which is expressed by the equation

$$A\,v_g = a\,v_o$$

v_g being the velocity of the gun or piston, and v_o being that of the oil, from which we get

$$a = \frac{A}{v_o}\,v_g$$

That is, the area of the orifice is equal to the constant factor $\frac{A}{v_o}$, multiplied by the velocity of recoil of the gun. Since the area of opening is thus proportional to the velocity of recoil, the same curve which we have already drawn will answer, by proper adjustment of the scale, as the curve of the area of opening of the orifice as a function of the distance from the initial point of the piston.

33 In this computation, I have paid no attention to the contraction of the liquid vein. The pressures which are used in the hydraulic cylinders of gun carriages are higher than those which are apt to be encountered in reservoirs from which the flow has been experimentally measured; with the ordinary high power gun and the recoil cylinders of size generally employed, the pressure runs from 1000 to 1500 pounds per square inch, while with mortars, which are lighter in comparison with the weight of the projectiles and therefore have a higher velocity of recoil, the pressure runs up as high as 4000 or 5000 pounds

per square inch. With such pressures the vein is considerably contracted, and we have used a coefficient as high as 1.67.

34 In the last experiments, with the mortar carriage, in which we used this coefficient we had difficulty in obtaining a proper indicator diagram, when we attempted as usual to check the theoretical work by the use of that instrument. The work was carefully gone over, and computations were made independently by several people, but we were unable to make the discrepancy disappear. Finally we dismounted the hydraulic cylinders and measured them with a star gage, when we found that they had been over-bored some 0.03 of an inch from the carefully prescribed diameter. The pistons were bushed so as to take up this unauthorized and unexpected clearance, and the trouble disappeared; the indicator diagram assumed a proper form; the science and the art of gun carriage construction were again on speaking terms with each other, and harmony reigned in the Ordnance Department.

35 In explaining some little of the methods which are followed in the work with which that department is charged, I have hoped that you would recognize some kinship between the workers in our class of problems and those who struggle with the problems of civil engineers, but when I tell you that the anxious designer finds himself puzzled and dismayed by what afterwards turns out to have been a workshop error on the part of those charged with working the design into material and, that holes are bored 0.03 of an inch larger than they ought to be, I expect you to say to yourselves: "These men are our brothers, their joys and woes are our very own."

36 The case of a recoil brake computation which I have hastily run over is the very simplest one; it meets with many variations in practice. The most simple variation is when the gun recoils up an inclined slide, down which it runs after recoil again to the firing position. In this case the hydraulic brake is assisted by gravity, which has to be taken into account in checking the recoil. Another common variation is when the gun carriage is so adjusted that the recoil of the piece is directly in the line of the axis, whether it be fired horizontally or at an elevation. With such carriages the piece is returned to the firing position by springs, which are compressed during recoil. If the gun be fired at an elevation the recoil is in this case assisted by a component of the force of gravity, and it is checked by the combined action of the hydraulic brake and the counter recoil springs. All of which produces a modification of the computation of the orifices for the flow of the liquid. An extreme case of variation exists in the disappearing carriage, upon which most of the guns of our seacoast fortifi-

cation are now mounted. An outline sketch of this carriage is shown in Fig. 9.

37 Many of you have seen carriages of this type, and others have perhaps seen illustrations and descriptions of them in various publications. I will however run briefly over the action which takes place when the gun is fired. The gun is mounted by its trunnions upon the upper extremities of two long levers; these levers are pivoted at their middle point in trunnion beds formed in a cradle, or top carriage, which is mounted upon rollers. To a bar joining the lower extremities of the two levers is attached a counterweight, sufficient to overbalance the gun, and these lower extremities are connected with a sort of cross-head which runs on vertical guides.

38 When the recoil takes place the middle point moves to the rear in a line parallel to the surface upon which the rollers run, while

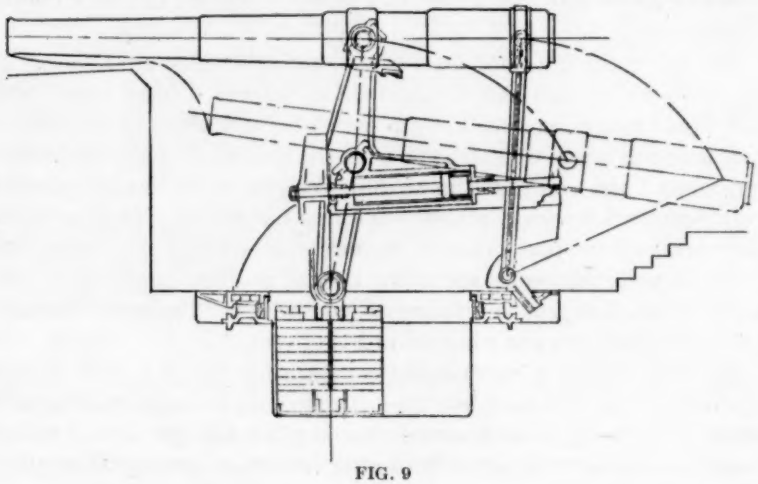


FIG. 9

the lower extremities of the levers move vertically upward in a straight line. It follows that the upper extremities, upon which the gun is mounted, move to the rear and downward in the arc of an ellipse. The breech of the gun is raised and lowered, for changing the elevation to correspond to the range, by two elevating arms which also serve to guide the breech during recoil, their point of attachment to the gun describing the arc of a circle. The recoil is checked partly by raising the counter-weight, but mainly by the hydraulic brake formed in this case by cylinders which are drawn over fixed pistons. It will be observed that this carriage offers a very considerable departure from the simple case in which the gun recoils horizon-

tally in a line parallel with the axis of the brake cylinder; the gun is set in motion in a line approximately parallel to the motion of the cylinder, but it changes its direction with reference to that motion at every instant, and it moves finally nearly at right angles to it; the levers upon which the gun is mounted have both a motion of translation and a motion of rotation; the elevating arms have a motion of rotation about their lower extremities; the counter-weight moves upward in a direction practically at right angles to that of the brake cylinder. All of these masses, set in motion with different and constantly varying velocities of translation and rotation, must be brought to rest by the action of the hydraulic brake, in which the orifices should be so computed as to make its action constant.

39 There is thus offered a problem sufficiently complex to afford an abundance of interesting occupation; its solution involves the handling of equations involving some fifty terms, and the computation of the curve of variation of the orifices for the flow of the liquid is an operation requiring some ten days of close work.

40 We owe the method of computation which I have explained to General Sébert and Captain Hugoniot of the French Artillery; to which we are greatly indebted for scientific methods of ordnance construction. Indeed the French seem to have a peculiar genius for drilling into the future and extracting therefrom the hitherto unknown, and it is appropriate to mention here that we owe to them the rapid firing field gun with which the armies of the civilized world are today either already armed, or are rapidly rearming. The essential feature of this gun is its long recoil upon the carriage, something like four feet; by reason of which the action of the gun upon the carriage is so softened that the latter does not move from its place upon firing, and the gunner can sit upon the trail, with his eye at the sight, and continue the firing as rapidly as the piece can be loaded. This improvement raises the rate of fire from about two rounds per minute to about twenty.

41 Mechanical science and art have of course greatly advanced in the last half century. The structures have increased enormously in power and performance, and have also increased greatly in complexity and refinement, necessitating more extensive, more accurate, and more highly cultivated knowledge upon the part of designers, and enormous increase in the number of draftsmen required to translate the thoughts of the engineer into pictorial language, which can be understood by the mechanics who are to execute those thoughts, and a corresponding increase in the power and accuracy of the machines which have to fashion the material into shape, and the skill of the

persons who must operate them. Progress, in all subjects, has been defined to be the advance from the simple to the complex; and ordnance construction has shared in the progress, as thus defined, of other branches of engineering.

42 The most powerful gun of our Civil War period was the 15-inch Rodman smooth bore, firing a projectile of 480 pounds weight with a velocity of about 1500 feet per second. The drawings of this gun occupied but a single sheet, and the specifications for its manufacture could be written upon a single page. The drawings for the carriage upon which it was mounted cover two sheets of ordinary size, and the specifications cover less than half a dozen pages of ordinary handwriting. The drawings of the 12-inch built-up gun of today require about seven sheets for their representation, and the specifications are found in a printed pamphlet of some twenty pages. The sheets of drawings of the gun carriage number about twenty-five, closely covered with details, and the specifications, divided into two classes, general and special, occupy two printed pamphlets of 15 and 35 pages, respectively. The gun throws a projectile of 1000 pounds weight with a velocity of 2500 feet per second and an energy six times that of the projectile of the 15-inch smooth bore; while the rate of fire is increased from about one round in ten minutes to three rounds in two minutes. That is to say, about one hundred times as much energy can be delivered in a given time. The increase of extent and complication of the personal machine by which this result is accomplished can be appreciated by the members of similar organizations.

43 I will say a word or two about our special organization. The statutory strength of the Ordnance Department in officers is 85. Its officers are not graduated into it directly from the Military Academy at West Point, but all must serve for at least a year before being eligible for service in it. Service in the Department is by detail for four years at a time, after which captains and lieutenants must serve for at least one year in the branch of the service from which they were detailed, before being eligible for another tour. Majors and higher officers serve also four years at a time, but there is no compulsory interval between successive details; so that their service may be continuous, although it is not necessarily so. Detail to the Department, for the first tour of duty therein, follows an examination, which is either qualifying or competitive depending upon whether the number of candidates is less or greater than the number of vacancies; in the past there has usually been competition, which has often times been as great as corresponds to seven or eight times as many candidates as vacancies. Detail for subsequent tours of duty is made by a board of

Ordnance Officers, all senior to the grade eligible for the detail. The incentive to preparation for the examination, and for such continued effort as to merit re-detail to the Department, is found in the advancement of grade which may accompany the detail; officers of all grades in the army being eligible for detail to the next higher grade in the Ordnance Department, of which the lowest rank is first lieutenant If an officer once admitted is found not to be well fitted for the service, he need not be detailed for a second tour. There is thus a process of selection and elimination, with incentive, which constitutes a merit system. All officers, whether graduates of West Point or commissioned from civil life, are eligible.

44 The art of manufacture of ordnance is carried on at six large establishments, employing over 5000 workmen, of which 790 are machinists; the establishments are guarded and generally cared for by some seven hundred enlisted men. There are on the rolls of the department 90 draftsmen. At the Watertown Arsenal, near Boston are manufactured seacoast gun carriages; at the Springfield Armory, also in Massachusetts, the principal output is the musket, of which the plant has a manufacturing capacity of 400 per day of eight hours; at the Watervliet Arsenal, opposite Troy in New York, there are manufactured cannon, both large and small; at the Frankford Arsenal in Philadelphia, the principal manufacture is ammunition for small arms, but there is also made a considerable quantity of ammunition for small sized artillery and instruments for the fire-control and direction of artillery; at the Rock Island Arsenal in Illinois, the largest of them all, there are manufactured field artillery gun carriages and other vehicles, the personal and horse equipments for infantry and cavalry, artillery harness, and small arms. For the last, the plant has a capacity of about 250 guns per day of eight hours. All of the artillery material is tested and admitted to the service at the Sandy Hook Proving Ground, in New Jersey, which also forms a practical school to which officers are sent when first detailed for duty in the department. A powder factory, for the manufacture of smokeless powder, with a capacity for about 1000 pounds per day, is in process of erection upon a reservation near Dover, New Jersey.

45 I hope the organization is one which can commend itself to the thoughtful citizen, when described to him, as one in which strenuous and wholesome effort and keen competition must necessarily be found, and to which he is willing to confide the large expenditure and vital interest involved in the preparation of the fighting material for defence.

46 I wish to anticipate a suggestion which may possibly be made, tending to separate the class of military engineers from those who

work in civil pursuits. Your lives are spent in an effort to improve the facilities of the world for increasing the happiness and promoting the general well-being of its inhabitants. You build great connecting links to enable people on one side of enormous obstacles to pass conveniently and safely to the other side; you provide means of wonderful efficiency whereby hundreds of thousands of people who are not where they want to be in this restless world, are transported daily with the speed of the wind to the places where they think they would rather be. You are even now emancipating these insatiable travelers from the necessity for combination, and are placing at the individual door a machine of infinite patience to wait during meal hours and sleeping time, and with no claim for consideration as to fatigue or ennui, until such time as the whim or convenience of its master may call upon it to carry him at railroad speed to any place to which other engineers may have built a practicable road.

47 In all this are you set apart from the military engineer who works to create means of destruction, and whose effort is not to promote the pleasure of life but to produce means for smashing and damaging, for maiming and destroying; whose utilization retards progress in the pursuit of happiness, and necessitates a process of recuperation before its interrupted course can be pursued again from the point at which it was cut off; who strives to make two projectiles fly where but one flew before.

48 It would be almost disloyal to the enlightened giver of this splendid shelter in which we find ourselves this evening to say a word of discouragement to the efforts for universal peace in which he has shown such a profound and serviceable interest; but those efforts are not best promoted by ignoring their limitations, and by maintaining in the face of much sincere conviction that wars may soon come entirely to an end. I believe in the utility of peace conferences. I appreciate the evidence that the one of 1899 at The Hague produced an arbitration convention which has already served good purposes; and I am satisfied that it is entirely possible, and more than probable that the next conference, already arranged at that place, may improve the International Court of Arbitration so that the submission of differences to it may be more easy and inviting, and the failure to do so may be a more direct and responsible challenge to the public opinion of the world than at present. But we have only to consult history, and not very ancient history at that, to find instances of conflict in which arbitration would have been in no wise possible. The very latest of the great wars affords an example.

49 When the peace conference of 1899 first assembled at The

Hague there was an effort made to induce the powers represented to make a binding agreement that they would submit certain classes of dispute to arbitration. When this effort failed there were substituted for its expression in the treaty of arbitration various forms of moral pressure, designed to promote a resort to this method of settling differences. The most pronounced of these forms of pressure was that embodied in Article 27 of the treaty, which declared that whenever two nations should be involved in a dispute which threatened to become acute, it should be the duty of all the other signatory powers of the treaty to remind these two that the Court of Arbitration was open to them. The article was made prominent by considerable discussion before its acceptance; but no single power considered it worth while to fulfill the duty which it had engaged to perform, by reminding either Russia or Japan that the civilized world looked to them to carry their causes of disagreement before The Hague tribunal and abide by the result. It was in this case recognized that arbitration was not possible; but I think that we can find in comparatively recent history lessons which go farther than this one, and show that in certain cases arbitration is not only impossible but would be undesirable.

50 Our war with Spain was based upon the conceived necessity for terminating the rule of her government in Cuba; we believed that her incapacity for keeping order, for providing for the security of life and property, and for preserving livable conditions in general had been so demonstrated that it was necessary to use the land and naval forces of the United States to terminate her jurisdiction therein, and deny her further sovereignty over the island. What must have been the action of a court of arbitration upon this proposition? Courts must be guided by the law and the precedent and the established order as they exist at time of trial of the case. Our contention was to terminate the possession in which Spain was firmly established by all the rules of international law. No court, whatever its sympathies or views of the general welfare might have been, could have found justification, in any of the principles to which it would have had to look for guidance, for decreeing that Spain's lawful ownership of Cuba must come to an end against her will, and that the disposition of the island, either for annexation, autonomy or independence should be turned over to the United States. There is no process which a court could have considered by which the final result might have been brought about, against Spain's protest, except that of war. If the result was desirable, here is a case in which war served a better purpose than could have been served even by a court sympathizing with the object, but guided by its conscience and by its oath.

51 Nearly half a century ago the people of a part of these United States made up their minds finally that slavery was wrong, and should not be extended; the people of another section were equally positive and sincere and conscientious in their conviction that slavery was right and ought to be extended. The Supreme Court of the United States, following the Constitution and the statutes, found itself compelled to decide that slaves were property, and as such could be taken by their owners into the new territory of the United States, to be there entitled to its protection.

52 In the solution of this difference there was involved the question of the right of a state to withdraw from the Union. A distinguished son of Massachusetts, a veteran soldier on the Union side of the Civil War, has recently made a careful argument to show that the question of secession was not decided, was not intended to be decided and was recognized as being impossible of decision, at the time of the formation of this government. If this learned gentleman is right, and if the Supreme Court of the United States was right, the settlement of one phase of the great Civil War question by judicial process must have been entirely uncertain, and the settlement of the other, and morally speaking by far the more important phase, would undoubtedly by such process have been adverse to the conclusion which was finally reached, and of the righteousness and general benefit of which there is now no shadow of doubt in any portion of the entire civilized world.

53 In 1877 Russia went to war with Turkey in order to compel that nation to bring to an end the barbarities which were being inflicted upon the Christian people of the Balkan Provinces. In accordance with international law, Turkey was sovereign in those provinces and had the right to treat her subjects therein in accordance with the dictates of her own conscience. The war smashed this right, and brought to an end the Bulgarian atrocities, effecting the practical independence of Bulgaria. The results of the war alone would have been better than those finally secured, when a deliberative conference at Berlin partially undid the work of the sword, and left Macedonia in a subject position, to be the source of future trouble.

54 The American colonies went to war with the mother country in resistance to the principle of taxation without representation. During the progress of the war it became evident that harmony and satisfaction would not be restored by concession on the part of Great Britain of the main point contended for by the colonists. These concluded that nothing short of complete independence would satisfy their lofty aspirations and grant them that right of self-government

in the struggle which they were ready to embark their lives, their fortunes, and their sacred honor. Great Britain was very far from being ready to consider even practical, and far less complete and theoretical independence for the colonies. She had not yet learned the lesson as to the treatment of colonies which our Revolutionary War went so far in teaching her; though she never again treated other colonial dependencies as she had attempted to treat those in America, the lesson of the war was needed to show her that it was neither right nor possible nor profitable to treat colonies as regions to be drained of their wealth for the benefit of the home country. The principle of taxation without representation was well established by the usage of the world; it could not be upset by any process not revolutionary in its nature, while the withdrawal of the colonies from British sovereignty was completely beyond and without the pale of all law which could be laid down and followed, by any tribunal which could have been called upon to pass upon the situation. No court would have had any choice but to deny a petition for a decree of independence, if the colonists could have been wild enough to present such a petition, or could it have been possible to convene a court for receiving it. So the fathers declared that "When, in the course of human events it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth the separate and equal station to which the laws of nature and of nature's God entitle them, a decent respect for the opinions of mankind requires that they should declare the causes which impel them to the separation.

55 Here is the whole matter. A necessity is conceived for changing the organic law, by force if resisted and the only obligation resting upon those who decide to take the change into their hands is that they shall have such deference to public opinion as to set forth their case to the world and appeal to the right thinking for approval of their effort. If the independence of the United States was a good principle to be secured, here again is a case where war achieved a better result than could have been accomplished by arbitration.

56 It seems possible that one better skilled in the study of international law might evolve an acceptable generalization from these and other instances which could be found in history, and lay down a principle that the established order, as contained in the whole body of international law and usage, and custom, being the product of human wisdom is subject to being wrong, and to being found inapplicable to changed conditions and relations which arise in the progress of the world; that when such is found to be the case it is clear

that the existing law should be changed; but that when such change is resisted by a community whose interest is supposedly or actually bound up in the wrong order, there is no judicial process by which the change can be effected; that the process must be a revolutionary one, and that resistance entails that the revolution must be brought about by force, that is by war. And the people which has become satisfied that the change is necessary must state its case to the world, gird on the sword, and guided by its conscience and hoping for the approval of the public opinion of mankind, must resort to the only process by which that change which it believes makes for the highest good, can be accomplished.

57 In the cases cited in which the United States has been involved, it seems to me that thoughtful people must admit either that our country has been wrong, or that the outcome has been better than that which could have been granted by any court which it would have been possible to convene at the times when we entrusted our case to the God of Battles, in belief in the justice of whose decisions we hold up our heads today.

58 May I hope that you will concede that in passing our lives in the effort to improve the means for sustaining the nation's case in an appeal, in accordance with its conscience, for some great good which it is beyond the power of any court to grant, to an arbitrament of higher jurisdiction than that of any court, military engineers are not unworthy to be classed as workers with yourselves for the supreme good of the human race.

ENTROPY LINES OF SUPERHEATED STEAM

Taken from the Experiments of Knoblauch and Jakob

By ARTHUR M. GREENE, Jr., COLUMBIA, MO.
Member of the Society

The temperature entropy diagram is one of the most powerful aids n the study of the action of heat engines and it is of especial value in the investigation of engines, turbines, and refrigerating machines using volatile liquids as the working substance. For the cycles of refrigerating machines it may be applied rapidly to determine certain quantities and effects of proposed changes which would take considerable calculation; for the steam engine it may be applied to investigate the losses and interchanges of heat, while for steam turbines it may be used for the determinations of velocity in the different stages and to show how certain friction loss for one stage is available for the production of velocity change in the next stage.

2 The modern use of superheated steam for engines and turbines for the purposes of increasing the efficiency of the machines has necessitated the construction of accurate constant pressure lines in the superheated region of the entropy diagram for the investigation of the problems arising in the study of the heat interchange in the machine. It is true that one could figure out the net gain in pounds of coal per horse power without this but the detailed study can only be made when the lines are known.

3 These lines depend on the value of the specific heat of superheated steam at constant pressure, C_p. The value of this specific heat is necessary for the determination of the actual heat applied to bring steam into a given superheated condition. The value of C_p was considered as constant for a number of years, the value 0.48 determined by Regnault[1] being used. This was seen to be incorrect and a number of investigators attacked the problem. The results of Grindley and Griesmann seemed to indicate that the specific heat increased with the temperature and was independent of the pressure. This was

[1] V. Regnault, Mem. de l'Acad. des Sciences 26 p. 167, 1862.

To be presented at the Indianapolis Meeting (May, 1907) of The American Society of Mechanical Engineers, and to form part of Volume 28 of the Transactions.

found to be untrue in the various experiments of Lorenz, Linde, Holborn and Henning, Callendar, Carpenter, Knoblauch, and Jakob.[1] The results of the last named investigators are the best at hand and at present they should be accepted as correct.[2] The experiments have been carefully performed and the endeavor has been made to eliminate all errors. Their investigation is indeed an excellent piece of work. Their original paper gives reference to the works of others and explains the differences between the conclusions and results of the various experimenters.

4 The results of their work have been given in the Zeitschrift des Vereins Deutscher Ingenieure, Vol. 51, p. 81 and 124, 1907. In this paper a diagram and table are given showing the results of the experiments. These are reproduced in Fig. 1 and Table 1, and give the results in a graphical and tabular form. The curves are constructed by extrapolation from the results of the experiments.

5 The curves show the value of C_p for different temperatures at different pressures. The values are expressed in degrees centigrade and in kilograms per square cm. of pressure and in heat units per unit weight per degree which is an abstract number. The table gives the values determined from these curves. The variation of the specific heat is shown very clearly, and the great variation accounts for discrepancies which have appeared in work done in earlier times.

6 Let the curve shown in Fig. 2 be one of the curves of C_p for a given pressure with the axis drawn through the zero values of absolute temperature and of specific heat. The area beneath the curve between the temperature of saturation and the temperature T_2 is equal to the heat added to change one unit of saturated steam at that pressure from the point of saturation to superheated condition at the temperature T_2. The equation for that is

$$H = \int_{T_s}^{T_2} C_p dt \qquad [1]$$

and this is represented by the area $T_s T_2 A'' D$.

7 Equation 1 gives the amount of heat necessary for the change of one unit weight of steam from the saturation point to the superheated

[1]Grindley—Transactions of Royal Society, Vol. 194, Sec. A, 1900; Griesmann, Zeitschrift Des Vereins Deutscher Ingenieure, Vol. 47, p. 1852–1880; Lorenz, Zeitschrift des Vereins Deutscher Ingenieure, Vol. 48, p. 698; Holborn and Henning, Ann. d. Phys., 18 p. 739; Callendar, Proc. Royal Soc. of London, 67, p. 266, 1904; Carpenter, A. S. M. E., 1906–1907. See References by Knoblauch and Jakob.

[2]The results of A. R. Dodge, published in the April Proceedings of the Society indicates that C_p depends only on the pressure although the results of the work being done at the National Physical Laboratory of England show a change of specific heat with the temperature along a constant pressure line.

TABLE 1

VALUES OF SPECIFIC HEAT BY KNOBLAUCH AND JAKOB

Zeitschrift der Vereins Deutscher Ingenieure, Vol. 51

Values of C_p

Pressure p= Sat. tem.t=	0 kg.	1 kg. 99	2 kg. 120	4 kg. 143	6 kg. 158	8 kg. 169	10 kg. 179	12 kg. 187	14 kg. 194	16 kg. 200	18 kg. 206	20 kg. 211
Temp. sat.		0.463	0.480	0.513	0.548	0.583	0.621	0.660	0.704	0.751	0.807	0.865
t=100 C	0.447	0.463										
110 C	0.447	0.463										
120 C	0.447	0.462	0.480									
130 C	0.447	0.462	0.479									
140 C	0.448	0.462	0.477									
150 C	0.448	0.462	0.476	0.510								
t=160 C	0.449	0.461	0.475	0.506	0.545							
170 C	0.449	0.461	.474	0.502	0.536	0.582						
180 C	0.450	0.462	0.474	0.498	0.528	0.566	0.618					
190 C	0.451	0.462	0.473	0.495	0.520	0.552	0.594	0.648				
200 C	0.451	0.462	0.472	0.492	0.513	0.538	0.572	0.613	0.664	0.751		
t=210 C	0.452	0.462	0.472	0.489	0.507	0.526	0.553	0.583	0.616	0.668	0.750	
220 C	0.454	0.463	0.472	0.487	0.502	0.517	0.535	0.558	0.582	0.614	0.662	0.731
230 C	0.455	0.464	0.472	0.486	0.497	0.509	0.522	0.538	0.557	0.578	0.607	0.649
240 C	0.457	0.465	0.472	0.485	0.494	0.503	0.512	0.523	0.536	0.552	0.570	0.596
250 C	0.458	0.466	0.473	0.484	0.491	0.499	0.506	0.514	0.522	0.532	0.544	0.559
t=260 C	0.460	.467	0.473	0.483	0.490	0.496	0.502	0.508	0.514	0.520	0.527	0.535
270 C	0.462	0.468	0.474	0.483	0.489	0.494	0.499	0.504	0.508	0.513	0.517	0.522
280 C	0.464	0.470	0.475	0.483	0.488	0.493	0.497	0.501	0.505	0.508	0.511	0.514
290 C	0.467	0.472	0.477	0.484	0.489	0.493	0.497	0.500	0.503	0.506	0.508	0.510
300 C	0.470	0.474	0.478	0.485	0.490	0.493	0.497	0.500	0.502	0.504	0.506	0.508
t=310 C	0.473	0.477	0.481	0.487	0.491	0.495	0.498	0.500	0.502	0.504	0.506	0.507
320 C	0.476	0.480	0.483	0.489	0.493	0.496	0.499	0.502	0.503	0.505	0.507	0.508
330 C	0.479	0.483	0.486	0.491	0.495	0.499	0.501	0.503	0.505	0.507	0.508	0.510
340 C	0.483	0.486	0.489	0.494	0.498	0.501	0.503	0.505	0.507	0.509	0.510	0.511
350 C	0.487	0.490	0.492	0.497	0.500	0.503	0.506	0.508	0.509	0.511	0.512	0.513
t=360 C	0.491	0.494	0.496	0.500	0.503	0.506	0.508	0.510	0.512	0.513	0.514	0.516
370 C	0.495	0.498	0.500	0.503	0.506	0.509	0.511	0.513	0.514	0.516	0.517	0.518
380 C	0.499	0.502	0.504	0.507	0.511	0.512	0.514	0.516	0.517	0.519	0.520	0.521
390 C	0.504	0.506	0.508	0.511	0.513	0.515	0.517	0.519	0.520	0.522	0.523	0.524
400 C	0.509	0.511	0.512	0.515	0.517	0.519	0.521	0.522	0.523	0.525	0.526	0.527

point T_2. This value could be used in finding the total heat required to produce one pound of superheated steam from water at the freezing point by the formula

$$\text{Total heat} = q + r + \int_{T_s}^{T_2} C_p dt \qquad [2]$$

This expression could then be used to find the heat supplied to an engine or other machine and from it the efficiency could be found. However this may be for general problem of efficiency, many of the problems are best solved by means of the entropy diagram and for

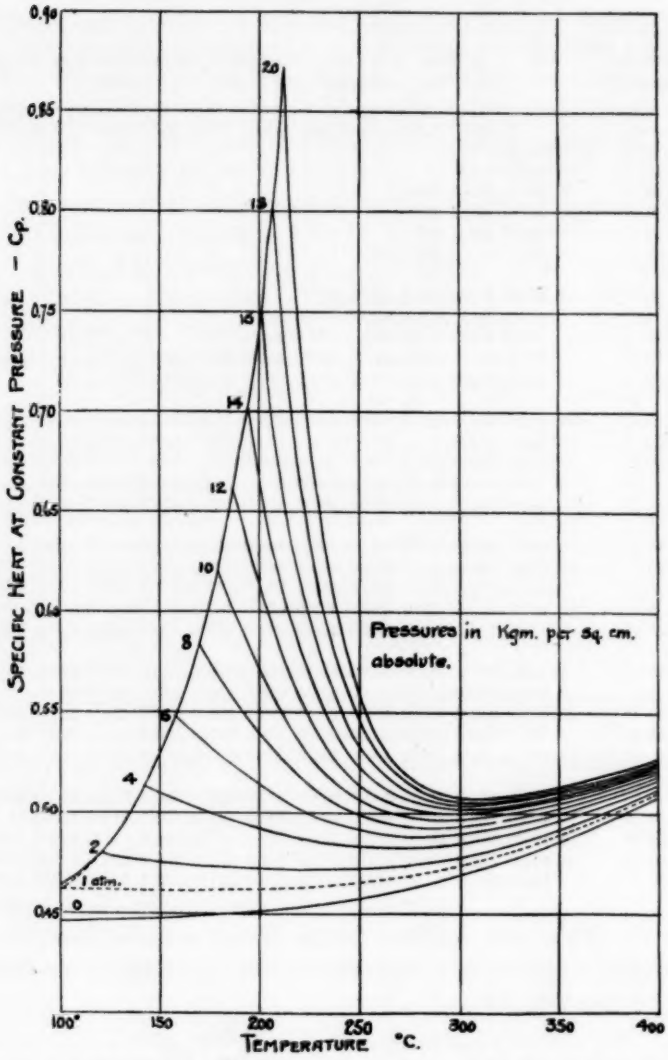


FIG. 1 VARIATION OF THE SPECIFIC HEAT OF SUPERHEATED STEAM

that reason it is necessary to construct the constant pressure lines in the temperature entropy diagram. From the definition of entropy it is known that the entropy change from the point of saturation to the point T_2 is

$$t_s\phi t_2 = \int_{T_s}^{T_2} \frac{C_p dt}{T} \qquad [3]$$

The integral in Equation 3 is the area of a curve whose ordinates have the value $\frac{C_p}{T}$ and whose abscissae are T.

8 A curve with ordinates $\frac{C_p}{T}$ may be constructed graphically as follows: From any point A in Fig. 2 draw a straight line to the origin. This cuts a vertical line through B at C. Let the distance OB be

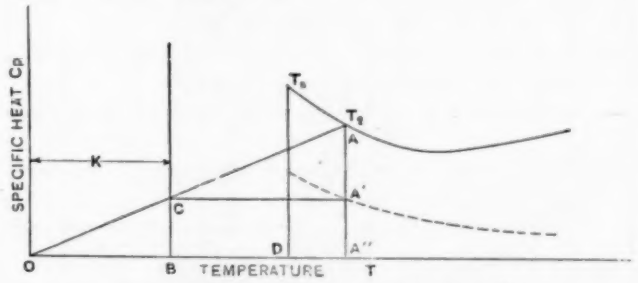


FIG 2 CONSTRUCTION OF CURVES FOR $\frac{C_p}{T}$

equal to K. Then since AA'' is equal to C_p and OA'' equals T, $BC = \frac{KC_p}{T}$. Draw a horizontal from C to the vertical line A, this cuts AA'' in A', the distance from the axis being $\frac{KC_p}{T}$. If a number of points A' are constructed in this way a dotted curve is formed whose ordinates have the value $\frac{KC_p}{T}$ and whose abscissae are T. The area of this for the limits of temperature above is

$$\text{Area} = \int_{T_s}^{T_2} \frac{KC_p}{T}\, dt = K \int_{T_s}^{T_2} \frac{C_p dt}{T} = K t_s\phi t_2 \qquad [4]$$

$$t_s\phi t_2 = \frac{Area}{K} \qquad [5]$$

9 Since the absolute zero is so far to the right, the simpler and more accurate method is to compute the values of $\frac{C_p}{T}$ and plot these. This has been done for the values of Table 1 and the values are given in Table 2 and Fig. 3. The limits of the curves on the left are the points of saturation. The curves are for different pressures in kilograms per square centimeter, although curves for 3 pounds per square inch, 5 pounds per square inch and 10 pounds per square inch have been interpolated.

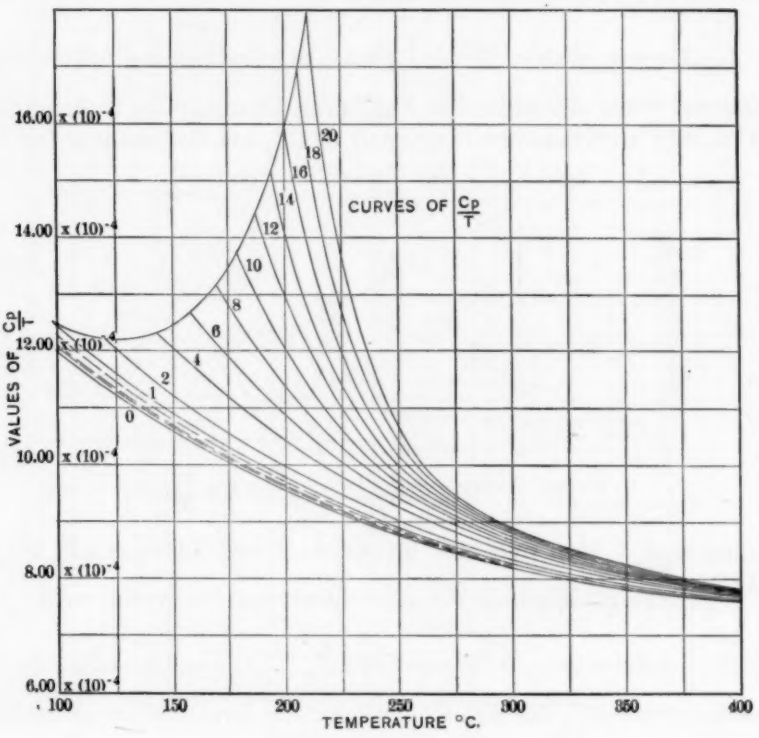


FIG. 3 CURVES FOR $\frac{C_p}{T}$

10 The reason for keeping the values in French units is the fact that the original data are given in those units and that the entropy lines will have the same numerical change in units of entropy between corresponding temperatures in the French and English systems since, as expressed, the unit entropy per unit mass is a ratio and has no dimensions. This would only change the units on the temperature

TABLE 2

VALUES OF C_p FOR STEAM AT DIFFERENT TEMPERATURES OF SUPERHEAT IN TEN THOUSANDTHS OF A HEAT UNIT PER POUND PER DEGREE PER DEGREE

Degree C.	Deg. abs.	0 kg.	1 kg.	2 kg.	4 kg.	6 kg.	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.
T. sat.	T. sat.		12.45	12.21	12.33	12.71	13.19	13.77	14.35	15.07	15.88	16.85	17.87
100	373	11.98	12.41										
110	383	11.67	12.09										
120	393	11.38	11.76	12.21									
130	403	11.09	11.46	11.89									
140	413	10.85	11.19	11.55									
150	423	10.59	10.92	11.25	12.06								
160	433	10.37	10.65	10.97	11.69	12.59							
170	443	10.14	10.42	10.70	11.33	12.10	13.14						
180	453	9.934	10.20	10.46	11.00	11.66	12.50	13.64					
190	463	9.741	9.978	10.22	10.69	11.23	11.92	12.83	14.00				
200	473	9.535	9.767	9.979	10.40	10.85	11.37	12.09	12.96	14.04	15.88		
210	483	9.358	9.565	9.772	10.12	10.50	10.89	11.45	12.07	12.75	13.83	15.53	
220	493	9.209	9.392	9.574	9.878	10.18	10.49	10.85	11.32	11.81	12.46	13.43	14.83
230	503	9.046	9.225	9.384	9.662	9.881	10.12	10.38	10.70	11.07	11.49	12.07	12.90
240	513	8.908	9.064	9.201	9.454	9.630	9.805	9.981	10.19	10.45	10.79	11.11	11.62
250	523	8.757	8.910	9.044	9.254	9.388	9.541	9.675	9.828	9.981	10.17	10.40	10.69
260	533	8.630	8.762	8.874	9.062	9.193	9.306	9.418	9.531	9.644	9.756	9.887	10.04
270	543	8.508	8.619	8.729	8.895	9.006	9.098	9.190	9.282	9.355	9.448	9.521	9.632
280	553	8.391	8.499	8.589	8.734	8.825	8.915	8.987	9.060	9.132	9.186	9.241	9.295
290	563	8.295	8.384	8.472	8.597	8.686	8.757	8.828	8.881	8.934	8.988	9.023	9.059
300	373	8.202	8.272	8.342	8.464	8.551	8.604	8.674	8.726	8.762	8.796	8.831	8.866
310	583	8.113	8.182	8.250	8.353	8.422	8.491	8.542	8.576	8.611	8.645	8.679	8.696
320	593	8.027	8.095	8.147	8.246	8.314	8.364	8.415	8.465	8.482	8.516	8.550	8.566
330	603	7.944	8.010	8.060	8.143	8.209	8.275	8.308	8.342	8.375	8.408	8.425	8.458
340	613	7.879	7.928	7.977	8.059	8.124	8.173	8.206	8.238	8.271	8.303	8.320	8.336
350	623	7.817	7.865	7.897	7.977	8.026	8.074	8.122	8.154	8.170	8.202	8.218	8.234
360	633	7.757	7.804	7.836	7.899	7.946	7.994	8.025	8.055	8.087	8.104	8.120	8.152
370	643	7.698	7.745	7.776	7.823	7.869	7.916	7.947	7.978	7.994	8.025	8.040	8.056
380	653	7.642	7.688	7.718	7.764	7.825	7.841	7.871	7.902	7.917	7.948	7.963	7.979
390	663	7.602	7.632	7.662	7.707	7.738	7.768	7.798	7.828	7.843	7.873	7.888	7.903
400	673	7.563	7.593	7.608	7.652	7.682	7.712	7.741	7.766	7.771	7.801	7.816	7.831

TABLE 3

VALUES OF ENTROPY FROM SATURATION POINT TO TEMPERATURE T_2 IN UNITS OF ENTROPY PER POUND OR KILOGRAM

Pressures		1 kg.	2 kg.	4 kg.	6 kg.	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.	10 lb.	5 lb.	3 lb.
Sat. Sup.	Tem. Temp.	99	120	143	158	169	179	187	194	200	206	211	89.5	72.4	61
deg.C	deg. F														
100	212	.0012	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0143	.0345	.0492
110	230	.0135	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0382	.0581	.0727
120	248	.0254	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0609	.0805	.0951
130	266	0370	.0012	.....	.....	.....	.....	.....	.....	.....	.....	.....			
140	284	.0484	.0237	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0825	.1019	.1164
150	302	.0594	.0352	.0085	.....	.....	.....	.....	.....	.....	.....	.....			
160	320	.0701	.0463	.0204	.0025	.....	.....	.....	.....	.....	.....	.....	.1032	.1224	.1358
170	338	.0807	.0571	.0319	.0149	.0013	.....	.....	.....	.....	.....	.....			
180	356	.0910	.0677	.0431	.0268	.0141	.0014	.....	.....	.....	.....	.....	.1229	.1420	.1564
190	374	.1011	.0780	.0529	.0382	.0263	.0146	...0043	.....	.....	.....	.....			
200	392	.1110	.0881	.0643	.0492	.0380	.0271	...0187	.0087	.....	.....	.....			
210	410	.1207	.0980	.0755	.0599	.0491	.0388	.0317	.0221	.0148	.0065	.....	.1420	.1609	.1.52
220	428	.1301	.1077	.0855	.0702	.0598	.0500	.0434	.0344	.0280	.0210	.0147			
230	446	.1394	.1172	.0953	.0803	.0701	.0606	.0545	.0458	.0400	.0337	.0286	.1604	.1791	.1934
240	464	.1486	.1265	.1048	.0900	.0801	.0706	.0649	.0566	.0511	.0453	.0408			
250	482	.1576	.1356	.1142	.0996	.0898	.0806	.0749	.0667	.0616	.0560	.0520			
260	500	.1664	.1445	.1234	.1088	.0992	.0901	.0846	.0765	.0715	.0662	.0624	.1781	.1967	.2110
270	518	.1751	.1533	.1324	.1179	.1084	.0995	.0940	.0860	.0811	.0759	.0722			
280	536	.1837	.1620	.1412	.1269	.1174	.1085	.1032	.0952	.0904	.0853	.0816	.1953	.2138	.2280
290	554	.1921	.1705	.1499	.1355	.1262	.1175	.1121	.1042	.0995	.0944	.0908			
300	572	.2004	.1789	.1585	.1442	.1349	.1262	.1209	.1131	.1084	.1033	.0998	.2120	.2305	.2447
310	590	.2087	.1872	.1669	.1527	.1435	.1348	.1296	.1218	.1171	.1121	.1086			
320	608	.2168	.1954	.1752	.1611	.1519	.1433	.1381	.1303	.1257	.1207	.1178			
330	626	.2248	.2035	.1834	.1694	.1602	.1517	.1465	.1387	.1342	.1292	.1257			
340	644	.2328	.2115	.1915	.1775	.1685	.1599	.1548	.1471	.1425	.1376	.1341			
350	662	.2407	.2195	.1995	.1856	.1766	.1681	.1630	.1553	.1508	.1458	.1424			
360	680	.2485	.2273	.2074	.1936	.1846	.1761	.1711	.1634	.1589	.1540	.1506			
370	698	.2563	.2351	.2153	.2015	.1926	.1841	.1791	.1715	.1670	.1621	.1587			
380	716	.2640	.2429	.2231	.2093	.2005	.1920	.1871	.1794	.1750	.1700	.1667			
390	734	.2717	.2506	.2308	.2171	.2083	.1999	.1949	.1873	.1829	.1780	.1746			
400	752	.2793	.2582	.2385	.2248	.2163	.2076	.2027	.1951	.1907	.1859	.1825			
Pressures		14.2 lb.	28.4.lb	56.8 lb.	85.2 lb.	113.6 lb.	142.2 lb.	170.4 lb.	199.0 lb.	227.2 lb.	245.8 lb.	284.4 lb.	10 lb.	5 lb.	3 lb.

TABLE 4

HEAT IN B.t.u. PER POUND FROM SATURATION TO TEMPERATURE T_2

Pressures		1 kg.	2 kg.	4 kg.	6 kg.	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.
Sat. Sup.	Tem. Temp.	99	120	143	158	169	179	187	194	200	206	211
deg.C	deg. F											
100	212	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
110	230	11.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
120	248	21.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
130	266	31.9	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....
140	284	42.2	21.3	.....	.....	.....	.....	.....	.....	.....	.....	.....
150	302	52.5	31.6	7.5	.....	.....	.....	.....	.....	.....	.....	.....
160	320	62.8	41.9	18.0	2.2	.....	.....	.....	.....	.....	.....	.....
170	338	73.1	52.2	28.3	13.3	1.2	.....	.....	.....	.....	.....	.....
180	356	83.4	62.5	38.6	23.6	12.5	1.3	.....	.....	.....	.....	.....
190	374	93.7	72.8	48.9	33.9	23.8	13.6	...4	.....	.....	.....	.....
200	392	104.0	83.1	59.2	44.2	34.1	24.9	16.8	8.1	.....	.....	.....
210	410	114.3	93.4	69.5	54.5	44.4	36.2	28.1	20.4	13.7	6.0	.....
220	428	124.6	103.7	79.8	64.8	54.7	46.5	39.4	32.7	26.0	19.3	13.6
230	446	134.9	114.0	90.1	75.1	65.0	56.8	50.7	45.0	38.3	32.6	27.9
240	464	145.2	124.3	100.4	85.4	75.3	67.1	62.0	57.3	50.6	45.9	42.2
250	482	155.5	134.6	110.7	95.7	85.6	77.4	73.3	69.6	62.9	59.2	56.5
260	500	165.8	144.9	121.0	106.0	95.9	87.7	84.6	81.9	75.2	72.5	70.8
270	518	176.1	155.2	131.3	116.3	106.2	98.0	95.9	94.2	87.5	85.8	85.1
280	536	186.4	165.5	141.6	126.6	116.5	108.3	107.2	106.5	99.8	99.1	99.4
290	554	196.7	175.8	151.9	136.9	126.8	118.6	118.5	118.8	112.1	112.4	113.7
300	572	207.0	186.1	162.2	147.2	137.1	128.9	129.8	131.1	124.4	125.7	128.0
310	590	217.3	196.4	172.5	157.5	147.4	139.2	141.1	143.4	136.7	139.0	142.3
320	608	227.6	206.7	182.8	167.8	157.7	149.5	152.4	155.7	149.0	152.3	156.6
330	626	237.9	217.0	193.1	178.1	168.0	159.8	163.7	168.0	161.3	165.6	170.9
340	644	248.2	227.3	203.4	188.4	178.3	170.1	175.0	180.3	173.6	178.9	185.2
350	662	258.5	237.6	213.7	198.7	188.6	180.4	186.3	192.6	185.9	192.2	199.5
360	680	268.8	247.9	224.0	209.0	198.9	190.7	197.6	204.9	198.2	205.5	213.8
370	698	279.1	258.2	234.3	219.3	209.2	201.0	208.9	217.2	210.5	218.8	228.1
380	716	289.4	268.5	244.6	229.6	219.5	211.3	220.2	229.5	222.8	232.1	242.4
390	734	299.7	278.8	254.9	239.9	229.8	221.6	231.5	241.8	235.1	245.4	256.7
400	752	310.0	289.1	265.2	250.2	240.1	231.9	242.8	254.1	247.4	258.7	271.0
Pressures		14.2 lb.	28.4.lb	56.8 lb.	85.2 lb.	113.6 lb.	142.2 lb.	170.4 lb.	199.0 lb.	227.2 lb.	245.8 lb.	284.4 lb.

TABLE 4

HEAT IN B.t.u. PER POUND FROM SATURATION TO TEMPERATURE T_2

Pressures Sat.	Temp. Sup.	1 kg.	2 kg.	4 kg.	6 kg	8 kg.	10 kg.	12 kg.	14 kg.	16 kg.	18 kg.	20 kg.
		99° C.	120° C.	143° C.	158° C.	169° C.	179° C.	187	194	200	206° C.	211° C.
deg. C.	deg. F.											
100	212	0.8										
110	230	9.2										
120	248	17.5										
130	266	25.8	8.6									
140	284	34.1	17.2									
150	302	42.4	25.8	6.5								
160	320	50.7	34.4	15.7	2.0							
170	338	59.0	42.9	24.8	11.7	.8						
180	356	67.4	51.4	33.8	21.3	11.2	.9					
190	374	75.7	60.0	42.7	30.7	21.2	11.8	3.5				
200	392	84.0	68.5	51.6	40.0	31.0	22.3	14.9	7.4			
210	410	92.3	77.0	60.4	49.2	40.6	32.4	25.6	18.9	12.8	5.6	
220	428	100.6	85.5	69.2	58.3	50.0	42.2	35.9	29.7	24.3	18.3	12.9
230	446	109.0	94.0	78.0	67.3	59.2	51.7	45.8	40.0	35.0	29.7	25.3
240	464	117.3	102.5	86.7	76.2	68.3	61.0	55.3	49.8	45.2	40.3	36.6
250	482	125.7	111.0	95.4	85.0	77.3	70.2	64.7	59.3	55.0	50.4	46.9
260	500	134.1	119.5	104.1	93.9	86.3	79.2	73.9	68.6	64.4	60.0	56.8
270	518	142.5	128.0	112.8	102.7	95.2	88.3	83.0	77.8	73.7	69.4	66.3
280	536	151.0	136.5	121.5	111.5	104.1	97.2	92.0	86.9	82.9	78.7	75.6
290	554	159.4	145.1	130.2	120.3	113.0	106.2	101.0	96.0	92.0	87.8	84.8
300	572	168.0	153.7	138.9	129.1	121.8	115.1	110.0	105.1	101.1	96.9	94.0
310	590	176.5	162.3	147.7	137.9	130.7	124.1	119.0	114.1	110.2	106.0	103.1
320	608	185.1	171.0	156.5	146.8	139.7	133.0	128.0	123.1	119.3	115.2	112.3
330	626	193.8	179.7	165.3	155.7	148.6	142.0	137.1	132.2	128.4	124.3	121.4
340	644	202.5	188.6	174.1	164.6	157.6	151.1	146.2	141.3	137.5	133.5	130.6
350	662	211.3	197.3	183.1	173.6	166.6	160.2	155.3	150.5	146.7	142.7	139.8
360	680	220.2	206.2	192.0	182.6	175.7	169.3	164.4	159.7	155.9	151.9	149.1
370	698	229.1	215.2	201.1	191.7	184.9	178.5	173.6	168.9	165.2	161.2	153.4
380	716	238.1	224.2	210 2	200.8	194.0	187.7	182.9	178.2	174.5	170.5	167.8
390	734	247.2	233.3	219.3	210.1	203.3	197.0	192.2	187.5	183.9	179.9	177.2
400	752	256.3	242.5	228.6	219.3	212.6	206.3	201.6	196.9	193.3	189.3	186.6
Pressure		14.2 lb	28.4 lb	56.8 lb	85.2 lb	113.6 lb	142.2 lb	170.4 lb	199.0 lb	227.2 lb	245.8 lb	284.4 lb

axis in making this a diagram for the English system of units. To get the curves of entropy at points of pressures of an integral number of of pounds, interpolation is resorted to, which is shown in Par. 13.

11 The entropy curves for the liquid and for saturated steam are then constructed using the entropy values for saturated steam and for the liquid as found from Peabody's Steam Tables. To these curves have been added the changes of entropy from the saturation

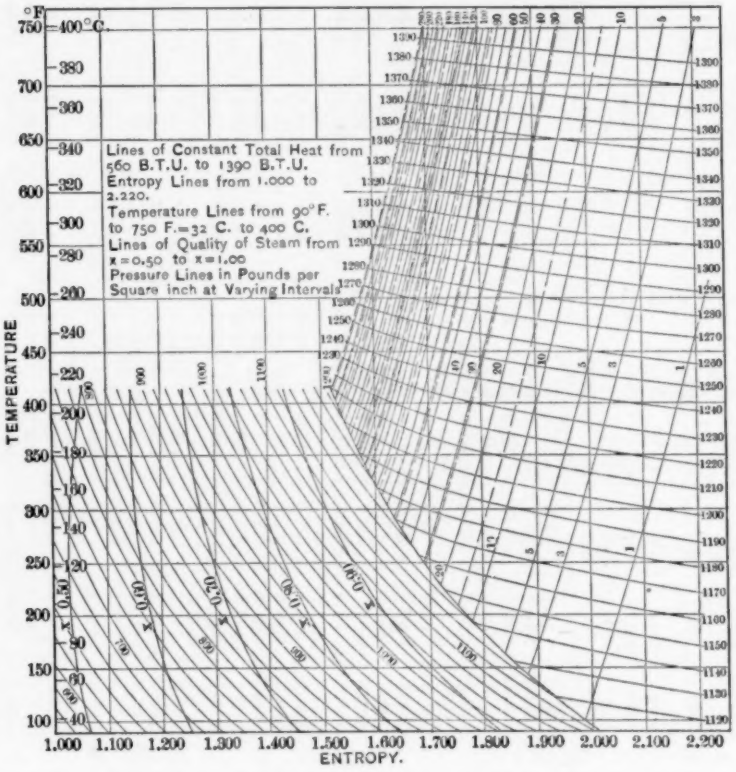

°F
°C.
Lines of Constant Total Heat from 560 B.T.U. to 1390 B.T.U.
Entropy Lines from 1.000 to 2.220.
Temperature Lines from 90° F. to 750 F.=32 C. to 400 C.
Lines of Quality of Steam from x=0.50 to x=1.00
Pressure Lines in Pounds per Square inch at Varying Intervals
TEMPERATURE
ENTROPY.
1.000 1.100 1.200 1.300 1.400 1.500 1.600 1.700 1.800 1.900 2.000 2.100 2.200

FIG. 4 LINES OF ENTROPY FOR SATURATED AND SUPERHEATED STEAM FROM PEABODYS STEAM TABLES AND THE SPECIFIC HEAT OF SUPERHEATED STEAM FROM KNOBLAUCH AND JAKOB

point to the various temperatures for the purpose of finding the total entropy change to each temperature. A rapid method of finding the area to the temperature T_2 on the $\frac{C_p}{T}$ curves without resorting to integration with a planimeter is to use the mean height of the curves for each 10 degrees. This is legitimate as the curvature of the lines is

very small. The values of the entropy change for the various pressures for a change from the point of saturation to the temperature T is shown in Table 3. This table is given for the purpose of showing values which may be laid off on any entropy diagram for saturated steam which differs from that derived from Peabody's tables.

12 The curves are laid off as shown in Fig. 4 and on it are placed lines of constant total heat which are of service in certain problems.

13 The lines for the pressures in kilograms are shown by faint lines. To find the lines for other pressures, lines were drawn in Fig. 5 in which the abscissae represented the entropy change from a given pressure line on any line of constant temperature and the ordinates represented the pressure corresponding to that change. In this manner lines were drawn for 750 degrees F. to 300 degrees F. at intervals of 50 degrees F. If now a horizontal line were drawn at any pressure in pounds per square inch the intersepts by these curves would give the change in entropy from one line of pressure to the desired curved constant pressure line at the different temperatures. From these values the curves of constant pressures for integral pounds per inch were drawn.

14 In the same manner lines for 10 pounds per square inch, 5 pounds per square inch, and 3 pounds per square inch were constructed in Fig. 3. From these the values of $\frac{C_p}{T}$ were measured and these gave the corresponding entropy lines in Fig. 4. The curves in Fig. 3 were completed by finding the value of C_p at the point of saturation by the formula of Knoblauch and Jakob.

$$(C_p)_{Sat.} = 0.41 + \frac{2.52 \times 10^8}{(T_k - T_s)^4} \qquad [6]$$

($T_k = 638\ C$ absolute = Critical Temp.)

and from it determining the end point of the curve.

15 The values of the heats added from the satuaration point to the various temperatures of superheat for the various pressures were found from the lines of specific heat by the method used in finding the entropy, and are given in Table 4. To these are added the total heat of the steam at saturation to find the total heat necessary to change a pound of water at the freezing point into steam at the superheated point when the pressure is kept constant. The heats at different temperatures were plotted and from these the temperatures corresponding to definite heats were found for the purpose of plotting the lines of constant heat.

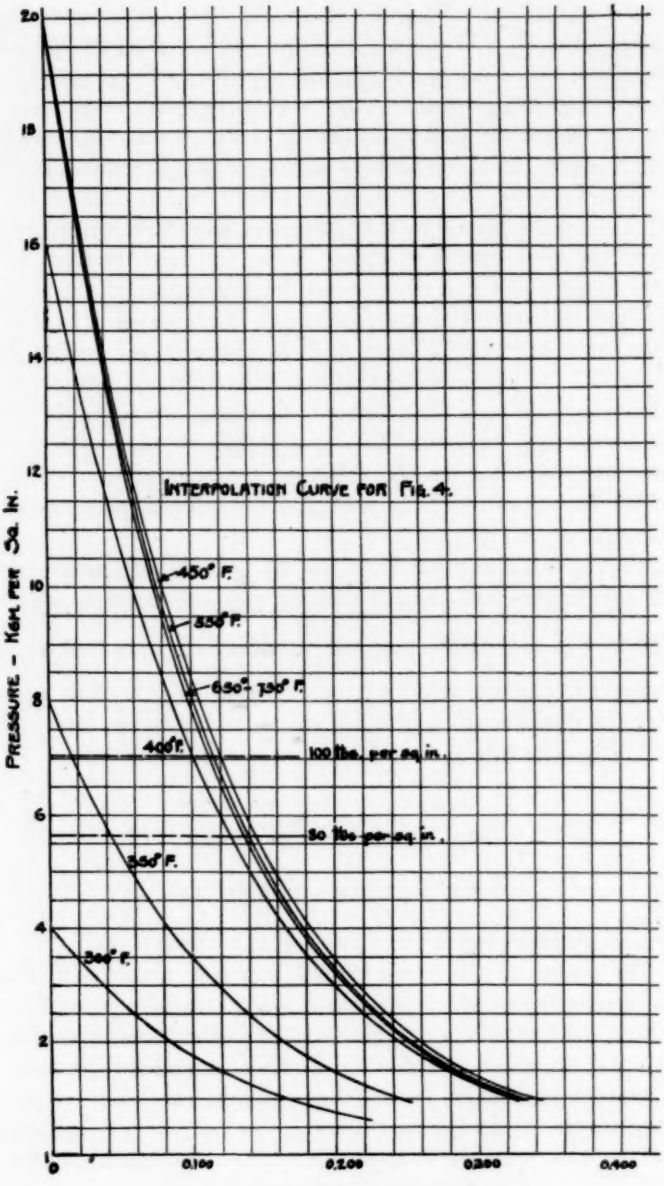


FIG. 5 CURVES FOR INTERPOLATION

16 The curves of total heat against temperature show first of all that the heats of saturation lie on a straight line according to the formula for total heat. The lines for different pressures show considerable variation from each other at these points. As the lines are carried into the superheated region they approach each other so that at a temperature of 750 degrees F. a variation of pressure from 280 to 15 pounds is produced by an addition of 9½ heat units. This shows that in the superheated region the total heat varies little with the pressure. As the temperature increases the superheated steam becomes more nearly a gas.

17 I wish to acknowledge my indebtedness to Mr. E. A. Fessenden of the University of Missouri for his assistance in drawing the plates and in aiding me in this work.

COST OF HEATING STORE HOUSES

Comparison with Cost of Dry-pipe and Calcium Chlorid Sprinkler Equipments

By H. O. LACOUNT, BOSTON, MASS.
Non-Member

In the work of the Associated Factory Mutual Fire Insurance Companies the problem of protecting store houses and their valuable contents against fire has required careful study. In nearly all classes of manufacturing properties experience has conclusively demonstrated that the automatic sprinkler, supplied with ample water, is the best means of protection. As is generally known, the automatic sprinkler has an orifice about ½ inch in diameter which under normal conditions is closed by a valve held in place by links or struts, so arranged that on the melting of some fusible solder the valve is liberated and water immediately discharged. For the average case, a temperature of 160 degrees F. is sufficient to open a sprinkler and the great work which the automatic sprinkler has done in reducing fire losses comes from the fact that it stands ready night and day instantly to deluge a fire with water at its start. The records show that the majority of fires are held in check, or even extinguished, by the opening of less than a half dozen sprinklers.

2 Long experience showed that store houses used for holding large amounts of cotton, wool, hemp, jute, together with the manufactured articles made from these stocks, and many other miscellaneous products, needed protection to prevent bad losses in much the same way that manufacturing buildings needed it. And again the automatic sprinkler was found the best device.

3 The larger part of the store houses, however, are not heated, so that in winter, water in the sprinkler pipes would freeze. This led to the development of several types of automatic valves which would permit draining water from the sprinkler system during cold weather

To be presented at the Indianapolis, Ind., Meeting (May, 1907) of The American Society of Mechanical Engineers and to form part of Volume 28 of the Transactions.

and filling the pipes with air under pressure. The valve, ordinarily known as a "dry-pipe valve," was so designed that on the opening of a sprinkler and the escape of the air, the valve would let in the water. Experience again has shown that with valves of certain types, properly cared for, reliable sprinkler protection can be obtained in this way, and a large number of such equipments have been put in.

4 Dry-pipe valves add appreciably to the first cost of the equipment. They require frequent attention while in service, and there is necessarily a delay, averaging perhaps a minute, between the opening of a sprinkler and the discharge of water, which means where there are inflammable contents, that the fire may spread, opening more sprinklers than would have been necessary had the first one instantly deluged the small blaze with water, the result being excessive water damage. Again, there is always the chance of a system being put out of commission for some time due to water freezing in the pipes in case they were filled and could not be promptly drained. For these reasons, it has always been considered preferable to have the full water pressure constantly on the heads, and this raised the question of the possibility of economically warming store houses just sufficiently to prevent freezing.

5 There was no question but that as a rule brick store houses could be warmed more easily and therefore at much less expense than those built of wood, but just what it would cost was not definitely known. This therefore, became the subject of investigation, and in 1901 the matter was referred to the Inspection Department, which is the engineering bureau for the Mutual Companies, and the work was carried on under the author's direction.

Two methods of procedure presented themselves:

a Apply certain formulae previously developed by several eminent German engineers and frequently used in such cases;

b Determine definitely by test the actual cost in one or more heated buildings.

6 In most calculations of heat required the normal inside temperature has usually been assumed to be about 70 degrees F., varying from say 50 degrees for rooms in which persons exercise vigorously to say 75 to 80 degrees for such rooms as in hot-houses. However, in store houses it is only necessary to maintain the temperature a few degrees above freezing, and as there seemed to be but little data on record from actual tests of such buildings it was decided to make tests as there was opportunity.

DIFFERENCE BETWEEN TEMPERATURES INSIDE AND OUTSIDE OF STORE HOUSE

7 In 1901 we did not know of any heated store houses where a test could be made of the actual amount of steam required to keep the temperature in such buildings above freezing, say at 40 to 45 degrees F., and therefore as a preliminary step, a series of tests were carried on during the winter of 1901–1902 in several store houses in different parts of the country to determine the average difference between the outside and inside temperatures of *unheated* buildings when used in the ordinary way for store house purposes.

8 It was assumed that the temperature inside light wooden buildings would necessarily closely follow the outside temperature and therefore this class of building was not included in the test, but only those of brick in which an appreciably higher inside temperature might be expected. However, buildings of different sizes were chosen to see what influence this item of cubical contents might have on the relative inside and outside temperatures, and by selecting store houses in different sections of the country a wide variation of weather conditions could be studied. With these points in mind the following mills were asked to coöperate in carrying on tests in buildings mentioned. Lewiston Bleachery & Dye Works, Lewiston, Me.; Nashua Manufacturing Company, Nashua, N. H.; Johnston Harvester Company, Batavia, N. Y.; Hamilton Manufacturing Company, Lowell, Mass.; Mount Vernon-Woodberry Cotton Duck Company, No. 1 Mill, Baltimore, Md. In every case the mill managements were very ready to give their assistance, and to them and to those men at the several plants who took the readings, looked after the thermometers, and kept the records, the credit for the success of this part of the work is very largely due.

9 Each mill was sent a Draper recording thermometer to be hung inside the store house; a maximum and minimum thermometer to be placed out of doors near the building, and a dated, loose-leaf note book, in which was to be recorded (twice a day), the readings of the outside thermometer, direction and force of wind (light, moderate, strong), condition of weather (fair, cloudy, snow, rain), and approximately how much of the time the outside doors were open. The dial from each recording thermometer, giving a week's record of inside temperature, together with the leaves from the note book corresponding to that week, were returned weekly.

10 From this data temperature curves were drawn for each store house, see Fig. 1, 2, 3, 4 and 5 inclusive, weather conditions being also

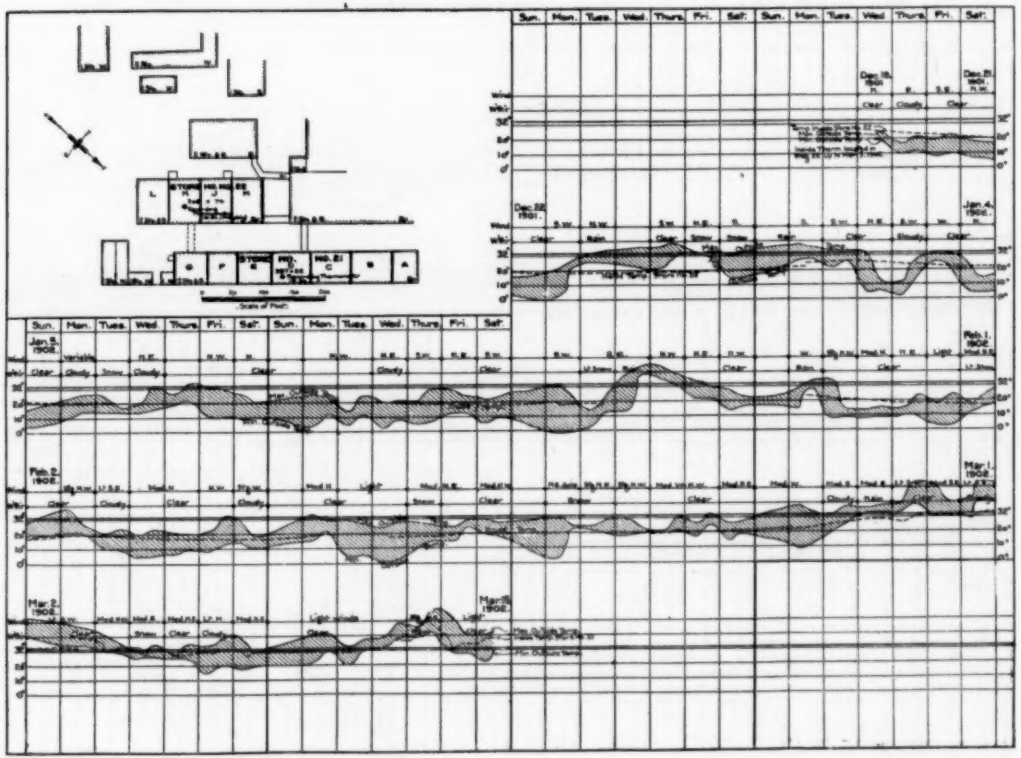


FIG. 1 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF LEWISTON BLEACHERY AND DYE WORKS

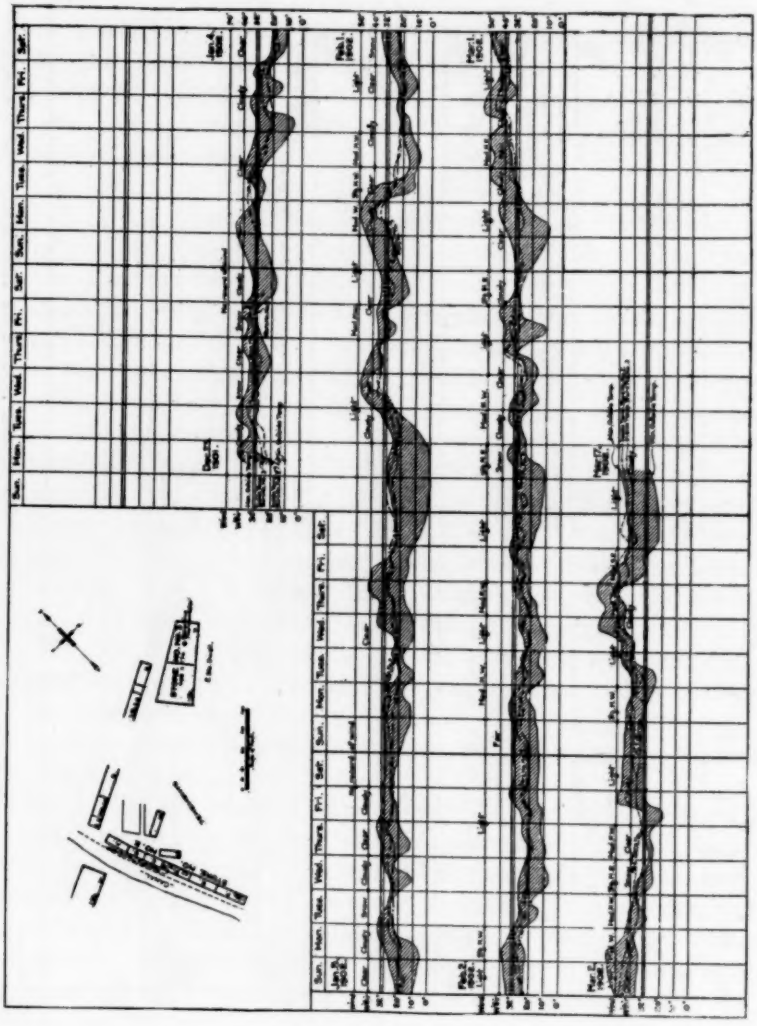


FIG. 2 RECORD OF TEMPERATURES UNHEATED STORE HOUSES OF NASHUA MFG. CO.

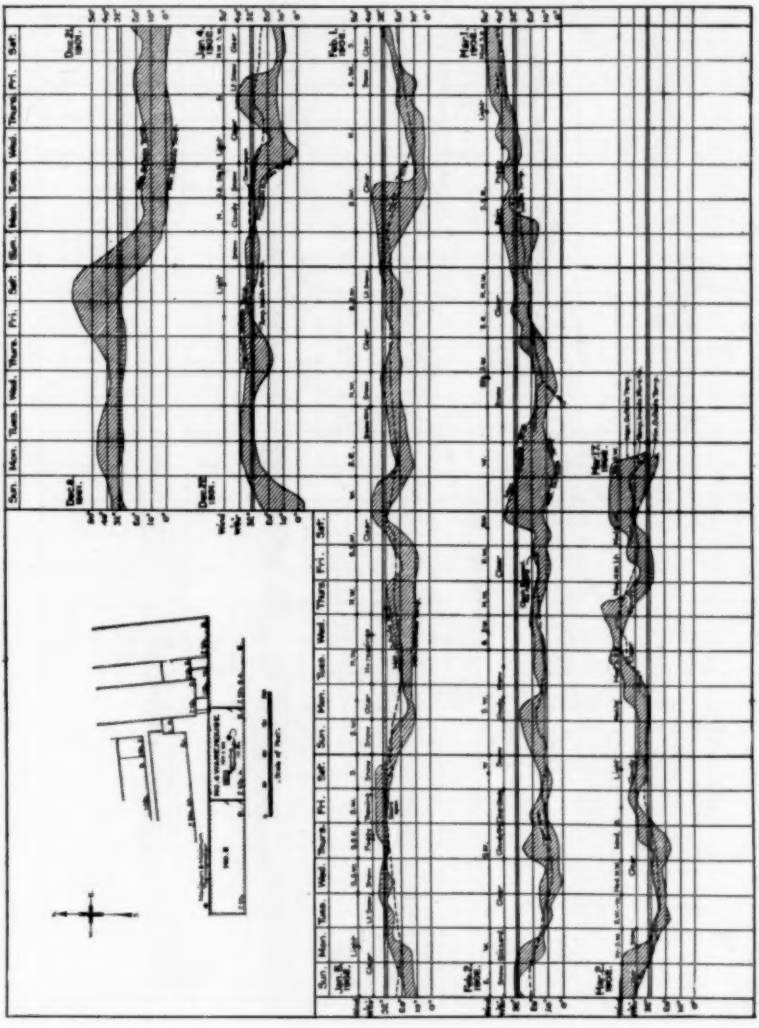


FIG. 3 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF JOHNSTON HARVESTER CO.

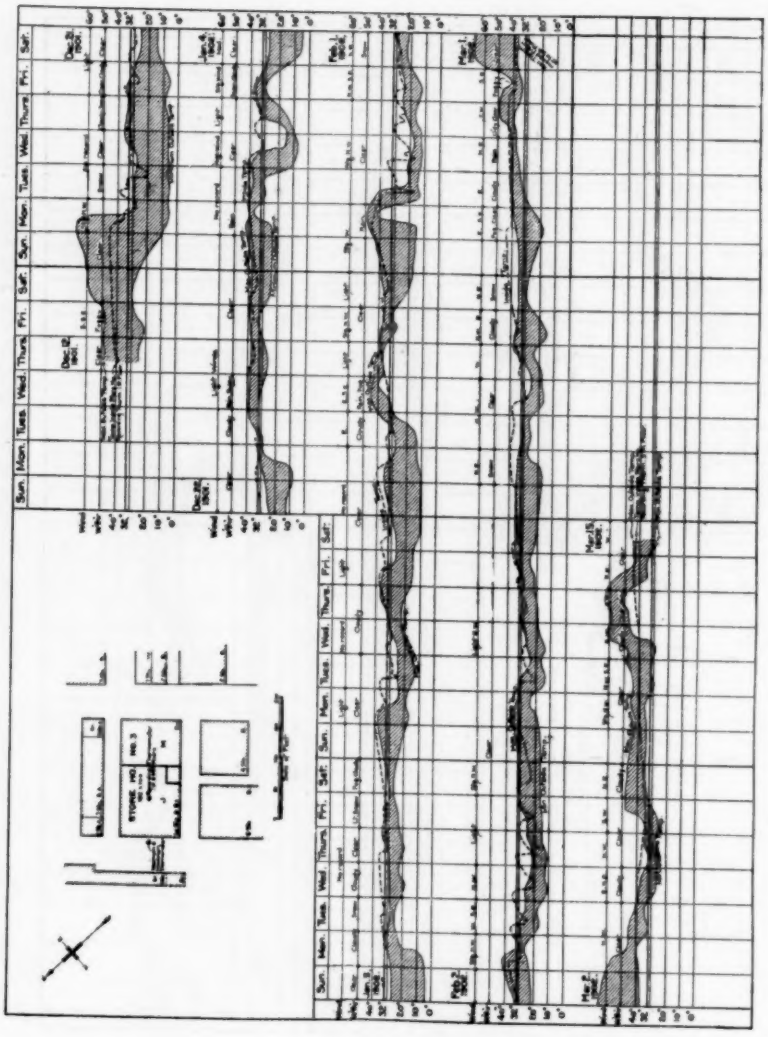


FIG. 4 RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF HAMILTON MFG. CO.

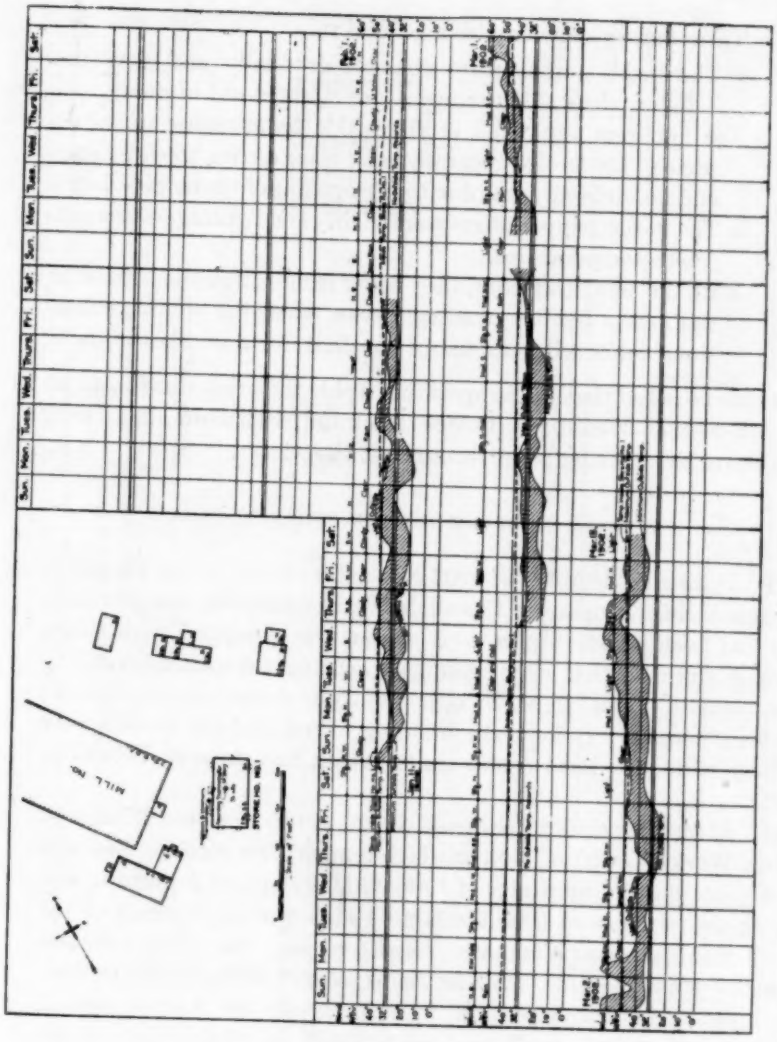


FIG 5. RECORD OF TEMPERATURES AT UNHEATED STORE HOUSE OF MT. VERNON WOODBERRY COTTON DUCK CO., MILLS 1 AND 3

indicated thereon. A plan of each property in the vicinity of the store houses under test is also given, showing roughly to what extent, if any, the store house was shielded from the wind by the neighboring buildings.

These curves show that as a general rule,

a The inside temperature changes gradually and does not follow the sudden temperature changes out of doors.

The apparent rapid fall of the inside temperature shown in some of the houses generally took place during the forenoons and undoubtedly was due to the opening of the outside doors.

b The inside temperatures were a fairly good average of the outside temperatures.

With but few exceptions, they never reach either the highest or the lowest outside readings, even when the outside conditions remained reasonably constant for a number of days.

It is to be noted that the temperature inside the brick store house at the Mt. Vernon-Woodberry Cotton Duck Co., Baltimore, Md., kept well above the freezing point throughout the winter.

TESTS OF STEAM HEATED STORE HOUSES

11 During the summer of 1902 No. 3 store house of the Hamilton Manufacturing Company of Lowell, Mass., in which temperature readings had been taken the previous winter, was equipped with steam heating pipes, so that water could be kept on the sprinklers during cold weather. This offered an opportunity to determine the amount of steam necessary to keep the building warm, and the owners were entirely willing to have a test made, which was done in February, 1903.

12 About this time store house No. 22 of the Lewiston Bleachery & Dye Works, Lewiston, Me., in which temperature readings had also been taken during the winter of 1901–1902, was piped for steam, and during the summer of 1903 the large 4-section store house A of the Bates Manufacturing Company, Lewiston, Me., was built and also piped for steam heating. At the Androscoggin Mills, Lewiston, Me., the building known since 1903 as store house No. 6, was heated. These buildings gave additional opportunity to obtain data on the cost of heating, and in each case the owners readily consented to a test. Arrangements were therefore completed, for tests in these three store houses in January, 1904.

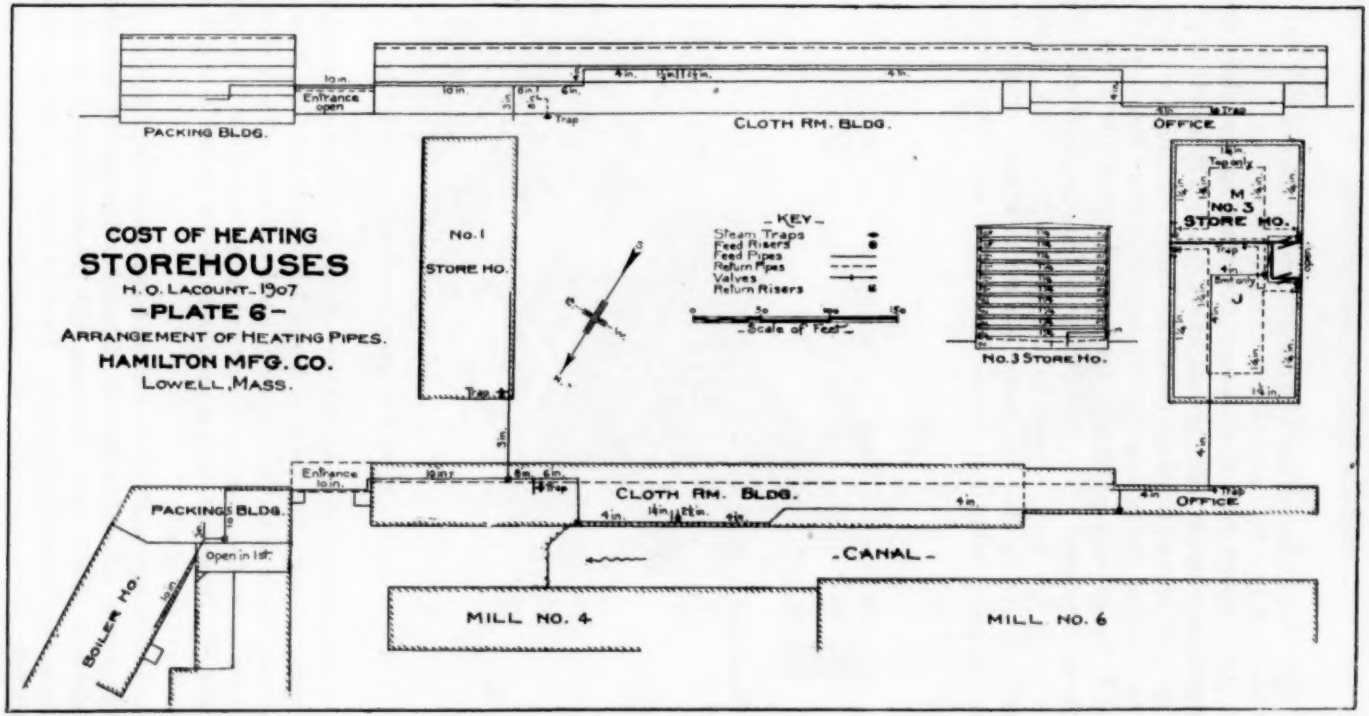


FIG. 6 ARRANGEMENT OF HEATING PIPES, HAMILTON MFG. CO.

DESCRIPTION OF BUILDINGS AND EQUIPMENT

13 The above four store houses and their surroundings, also arrangement of steam pipes, are shown on Fig. 6, 7, 8, 9 and 10.

The buildings and heating systems are briefly described as follows:

The Hamilton Manufacturing Company No. 3 Store House (see Fig. 6 and 7) was of brick, plank, and timber construction 100′ x 192′, ten stories and basement. The building was divided into vertical sections by a blank fire wall. Access to the several floors was obtained through double tin-clad fire doors in a common elevator and stair tower, the tower being open on one side out of doors. The surround-

FIG. 7 STORE HOUSE NO. 3, HAMILTON MFG. CO., LOWELL, MASS.

ing buildings were comparatively low, affording no wind protection to the upper stories. The building had a large number of windows of small area, made of ordinary glass in wooden frames. There were a few doors on the first floor for shipping purposes in addition to those in the tower. There were numerous cracks in the floors, due to the shrinking of the planks.

14 In the basement was a warm opener room about 100′ x 40′, which was not included in the test. The other floors contained cotton in bales and cloth in bales and cases, with the exception of two floors of one section, which were vacant. The store house was possibly two-thirds full.

15 The heating system consisted of one line of 1¼ inch pipe near the ceiling, about 3 feet from the outside walls of each floor, with an additional loop in the top floor under the roof. These pipes were supplied from two risers, one in each section, the lower half of each

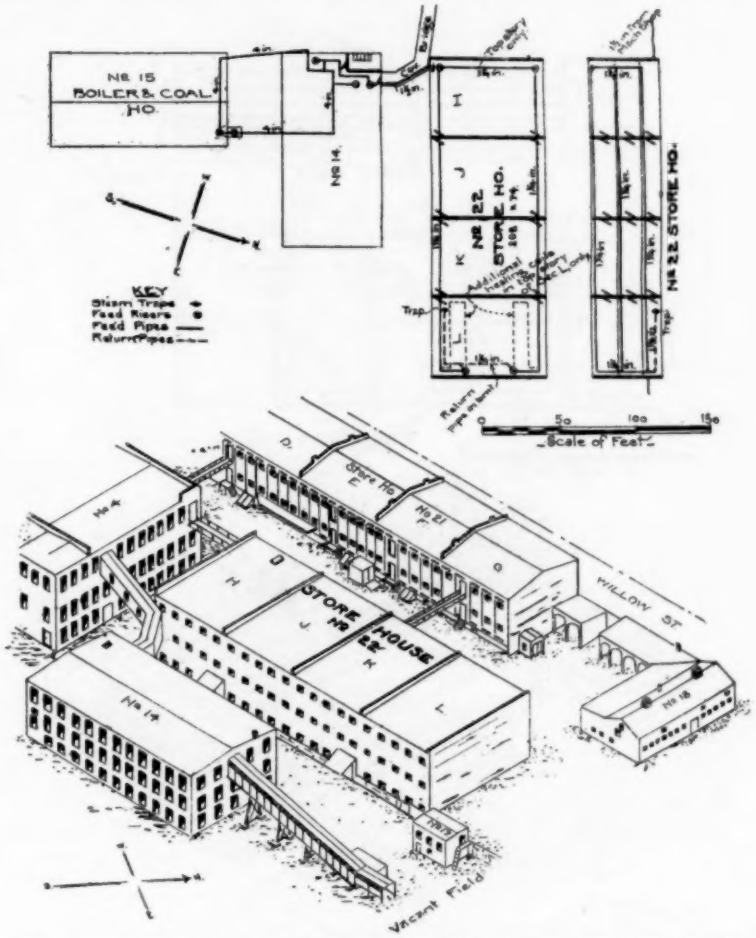


FIG. 8 STORE HOUSE NO. 22, LEWISTON BLEACHERY AND DYE WORKS, LEWISTON, ME.

riser being 3 inches, the upper half 2 inches. The pipes also connected with two drains, one for each section, the lower half of each being 2 inches, the upper 1½ inch. Steam could be cut off from any floor by gates at the risers, and as noted later, approximately every alternate floor was kept shut off during the test, which probably could not have

been done had it not been for the cracks in the floors, which allowed the heat from one story to pass into the one above.

16 The steam was taken from one of the main mill supply pipes and tapped at different points for various purposes. The distance

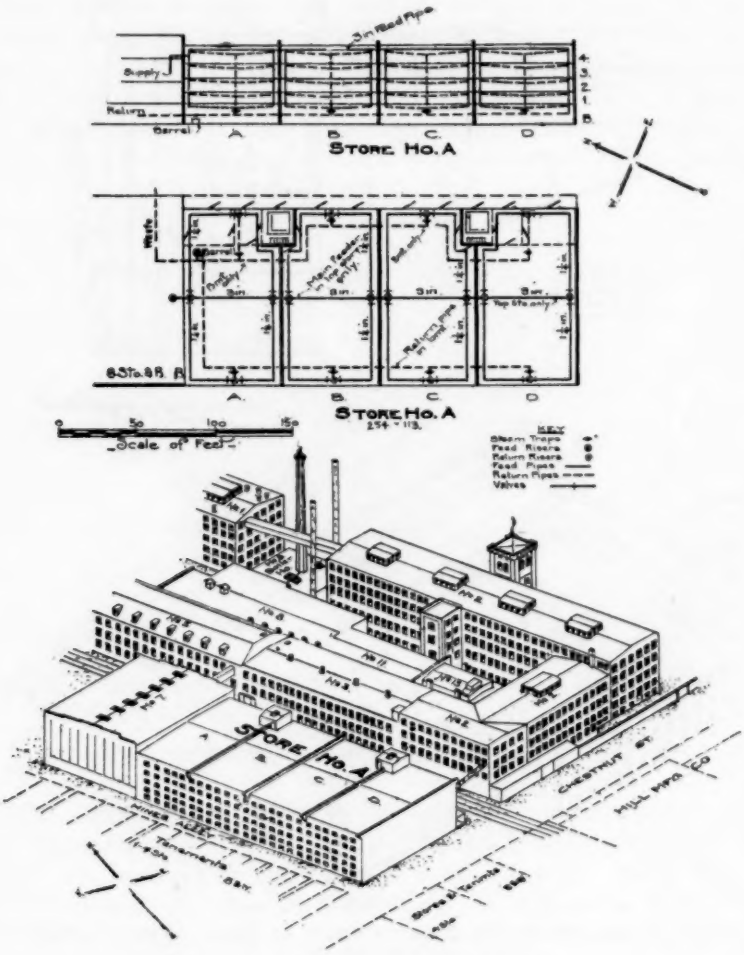


FIG. 9 STORE HOUSE A, BATES MFG. CO.

from the boiler house to the store house along the pipe was about 1200 feet; boiler pressure, 76 pounds; pressure at store house, 50 pounds. By means of a reducing valve at the point of entrance to the store house the pressure in the heating system was kept at 2 lbs. or less,

by gage, except for a few hours one afternoon, when the pressure was increased to from 6 to 10 lbs. in anticipation of an exceptionally cold night. The drain pipes from the heating system were run to one "dump" trap, which delivered all condensed steam into the barrels used in the test.

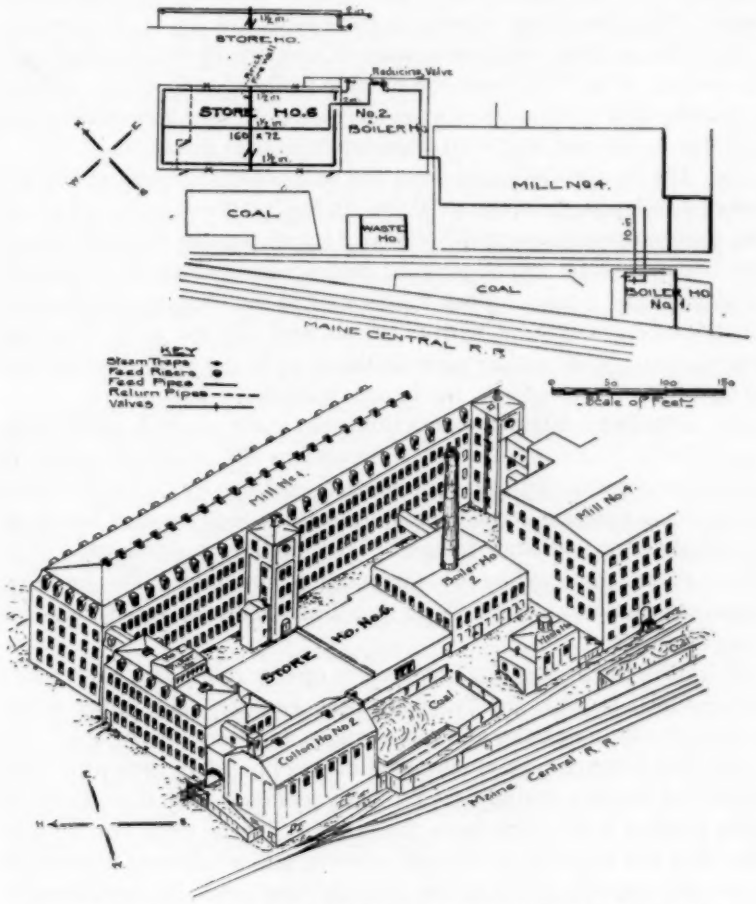


FIG. 10 STORE HOUSE NO. 6, ANDROSCOGGIN MILLS, LEWISTON, ME.

17 The Lewiston Bleachery & Dye Works store house No. 22 (see Fig. 8) was of brick, plank and timber construction, 74′ x 280′, two stories and basement, divided into four vertical sections by fire walls having double tin-clad fire doors at the openings. There were no openings between the basement and first floor, but from the first to

second floor were two open stairways and one open chute. The storehouse was shielded from the wind to some extent by buildings on three sides. The buildings had several windows, but of small area, made of ordinary glass in wooden frames, and there were four or five outside doors; the basement contained chemicals and miscellaneous storage, and the first and second stories cotton goods in bales and cases. The store house was about two-thirds full.

18 The heating system consisted of one line of 1¼ inch pipe near the ceiling, a few feet from the outside walls of each story, with an extra loop in the top story of one end section, to take care of the extra cold due to the roof and wind exposure from that direction.

19 The steam was taken from the mill boilers through about 175 feet of 4 inch pipe to a reducing valve in the basement of No. 14 building, thence through about 100 feet of 1½ inch pipe to the store house. The boiler pressure was 80 pounds; pressure in the heating system, 12 to 15 pounds by gage. Both 4 inch and 1½ inch supply pipes above mentioned were covered with magnesia and drained away from the store house. The heating pipes in the store house were drained into a trap which delivered into the barrels used in the test.

20 The Bates Manufacturing Company store house A (see Fig. 9) was of brick, plank and timber construction, 254′ x 113′, four stories and basement divided into four vertical sections by blank fire walls, access to the different floors being obtained through tin-clad fire doors in the elevator and stair towers. The building was protected from the wind to some extent by surrounding buildings. The building contained numerous windows of small area made of wired glass set in metal frames.

21 With the exception of two warm opener rooms, each 34′ x 22′, not included in test, the basement was vacant. The upper floors contained cotton in bales and cased goods, and were nearly full.

22 The heating system consisted of one line of 1¼ inch pipe near the ceiling running entirely around each section in each floor, the pipe being located a few feet from the walls. There were two supply pipes and two drain pipes for each section, and a sufficient number of gates were provided so that the heating pipes could be controlled in four divisions in each floor. In addition to the above, three radiators were placed in each section of the first floor along the northeast wall to prevent freezing of the water in the sprinkler pipes near the doors, which were necessarily opened from time to time when making or receiving shipments.

23 Steam was supplied from the mill boilers about 380 feet distant. The steam main for mill service was tapped a short distance from the

store house for a 3-inch supply for this heating system. The boiler pressure was 65 pounds, and at the entrance to the store house 60 pounds during the first part of the test, but during the final test the pressure was reduced to about 10 pounds by throttling the valve at the entrance, no reducing valve having been provided. The system was originally laid out with a trap at the bottom of each vertical drain pipe, these traps discharging into a common return drain. However they did not operate satisfactorily and were cut out and a large trap was inserted in the common return pipe for the tests, this trap discharging into the barrels.

24 The Androscoggin Mills No. 6 store house (see Fig. 10) was of wood, 160′ x 72′, one story high, having plank and timber roof and floor, and walls made of two thickness of boards, with two thicknesses of heavy building paper between them, a total thickness of 2½ inches. The building was divided into two vertical sections by a fire wall containing one opening, protected by a double tin-clad fire door. The building had four large windows, protected by outside storm windows. There were also two outside doors. The building contained mostly cotton in bales and was nearly full. The heating system consisted of one line of 1½ inch pipe located near the ceiling, a few feet from the outside walls, and an additional length of 1½ inch pipe through the center of the building.

25 Steam was taken from the No. 1 boiler plant through about 350 feet of 10 inch and 6 inch pipe, where it passed through a reducing valve located in No. 2 boiler house adjoining the store house. The boiler pressure was 95 pounds, pressure at entrance to store house, 15 pounds by gage. The condensed steam was piped to a trap in No. 2 boiler house, which was discharged into the barrels used in the test.

26 In working up the results of the tests on the above heated store houses it has been of interest to note the difference or similarity, as the case might be, between the several buildings and their equipments and to facilitate comparison, the following summary has been prepared in tabular form, giving in parallel columns certain data regarding size and construction of buildings, heating system, etc.

TABLE 1 SUMMARY OF DATA REGARDING HEATED STORE HOUSES

Items	Hamilton Mfg. St. H. No. 3	Lewiston Bl. and Dye Wks. St. H. No. 22	Bates Mfg. Co. St. H. "A"	Androscoggin Mills. St. H. No. 6
Location	One city block	Mill yard	Mill yard	Mill yard
City and State	Lowell, Mass.	Lewiston, Maine	Lewiston, Maine	Lewiston, Maine
Walls				
Material	Brick	Brick	Brick	Wood
Thickness in inches	30 to 16	20 to 16	20 to 16	2½
Size				
Ground plan dimensions in feet	192 x 100	208 x 74	254 x 113	160 x 72
Height above ground in feet	90	38 (av.)	40 (av.)	13
Depth below ground in feet	5	4	6	0
Number of floors	10 & bsmt	2 & bsmt.	4 & bsmt.	1
Sections				
Number vertical	2	4	4	2
Size of each in feet	(117x100 75 x 100)	52 x 74	64 x 113	72 x 80
Doors through party walls	None	1 each sec.	None	1
Stair and elevator tower				
Size in feet	20 x 20	None	2–22 x 22	None
Outside or enclosed	Outside	None	Enclosed	None
Framing, etc.				
Plank and timber	Yes	Yes	Yes	Yes
Width of bays in feet	8	10	8	8
Floor beams in inches	14 x 16	5½ x 15 and 12 x 14	10 x 16	
Floor planks in inches	3	3	4	
Roof beams in inches	10 x 12	3-3 x 12	6 x 14	8 x 8
Roof planks in inches		3	4	2
Cubical contents				
Exclud. tower not heated in cu ft.	1,786,000	646,464	1,275,764	149,760
Exclud. bsmt. and tower in cu. ft.	1,622,800	646,464	942,956	149,760
Per cent bsmt. to total cu. ft.	9	26	26	0
Outside surface exposed to cold in sq.ft.	75,360	36,824	56,028	16,616
Area of roof in sq. ft.	19,200	15,392	28,702	11,520
Per cent roof area to total area	26	42	51	69
Area of walls above ground exposed to cold in sq. ft.	56,160	21,432	27,326	5,096
Windows				
Total number and kind	565 single	109 single	92 single	4 double
Glass area in sq. ft.	3690	1207	1164	128
Avr. area per window in sq. ft.	6.5	11.05	12.6	32.0
Per cent glass area to wall area	6.5	5.6	4.7	2.5
Ratio glass area to cu. contents exclud. bsmt. and tower	1 to 440	1 to 396	1 to 810	1 to 117
Outside doors				
No. of	30	8	10	2
Estimated area in sq. ft	900	344	350	52
Per cent door area to wall area	1.6	1.6	1.41	1.02
Ratio door area to cu. contents exclud. bsmt. and tower	1 to 1803	1 to 1878	1 to 2690	1 to 288
Per cent total door and window area to wall area	8.15	7.23	5.54	3.54

TABLE 1—(Continued)

Items	Hamilton Mfg. Co. St. H. No. 3	Lewiston Bl. and Dye Wks. St. H. No. 22	Bates Mfg. Co. St. H. "A"	Androscoggin Mills St. H. No. 6
Ratio total door and window area to cubic contents (exclud. bsmt. and tower	1 to 354	1 to 416	1 to 623	1 to 830
Occupancy				
Sections contain	Mostly cotton in bales and cloth in cases	Bmt. chemicals and lumber 1 and 2 goods in cases	Bsmt. mostly vacant, ¼ cotton baled and cased goods	Baled cotton
Warm opener room in bsmt. contains	7 openers	No room	Openers	No room
Heating system				
Size of supply pipe in inches	3	1½	3	2
Size of circulating pipe in inches	1½	1½	1½	1½
Length of circulating pipe in feet	6529	1500	5590	636
Total heating surface including risers and drips in sq. ft.	3006	690	3730	316
Circulating pipe only sq. ft.	2781	605	2877	316
Per cent circulating pipe in top story	16.3	45	20.8	
Ratio heating surface in top story to area of roof	1 to 39	1 to 44	1 to 40	1 to 36
Ratio total heating surface to cu. contents exclud. tower	1 to 594	1 to 936	1 to 342	1 to 473
Ratio total heating surface to area of roof and walls (exposed to cold)	1 to 25	1 to 534	1 to 14	1 to 53
Per cent of heating surface used in test	58	100	75	100
Steam				
Pressure at boilers	76	80	65	95
Pressure at st .h.	50±	12 to 15	60 and 10	60
Pressure in st. h. system at reducing valve	1 to 2 (av.)	12 to 15	60 and 10	15 to 17 (av.)
Condition, general average	Superheated	Superheated	Primed	Superheated

METHOD OF TESTING

27 Except at the Hamilton store house, a short preliminary test was made in order to see that the conditions were favorable. This was then followed by the final test, the results of which are given later. The preliminary tests are not included in figuring the cost of steam used, but the readings taken are given. This preliminary test was of value, especially at the Bates store house, in that it showed at once that more steam was being used than necessary, and consequently the steam pressure was reduced for the final test. The tests at the Androscoggin and Lewiston Bleachery store houses, which were started Jan-

uary 8, 1904, were discontinued owing to the sudden rise of outside temperature and the prospect of a few warm days. The readings taken, however, are also given.

28 The method of determining the amount of heat used in the buildings was substantially the same in all cases, and consisted in:

a Noting pressure or temperature of the steam as it entered the system.

b Determining the condition of the steam from time to time by calorimeter tests.

c Weighing all condensed steam as it came from the heating pipes, night and day during entire test.

d Noting the temperature of the returned water.

From this data the British thermal units per hour used in heating the buildings could be found.

29 To determine the condition of the steam entering the heating systems of the store houses, tests were made with a "barrel calorimeter." For this purpose a wooden barrel on scales, and provided with a valve at the bottom for emptying, was used. The steam heating system was tapped on the low pressure side of the reducing valve or controlling gate valve by a small pipe, terminating in a short length of rubber hose. In some cases this pipe connection was several feet long and was very carefully jacketed with steam pipe covering to avoid condensation as far as possible.

30 The calorimeter test consisted in first weighing the barrel empty, filling it with cold water and again weighing it, noting also the temperature of the water. Steam was then allowed to blow through the small pipe connection above mentioned until it was warmed and all water had been blown out. The hose was swung into the barrel and the steam allowed to run into the water until a certain amount had been condensed. The steam was shut off, the water in the barrel well stirred, and the temperature noted. This test was repeated several times just before the final test was made.

31 From this data the condition of the steam may be determined by the use of the formula given in "Thermodynamics of the Steam-Engine," by Cecil H. Peabody, as follows:

If the pressure of the steam is p, and the part of each pound of the mixture which is steam is represented by X, while the initial and final temperatures of the water are t' and t'', and the weights of the water and steam are W and w, then

$$X = \frac{W(q''-q') - w(q-q'')}{wr}$$

r and q being the latent heat and heat of the liquid for the pressure p, and q' and q'' being the heats of the liquid for the temperatures t' and t''.

32 If the solution of the above formula shows $X = 1$, the steam is saturated; if greater than 1, the steam is superheated; and if less than 1, the steam is wet. While this method is not accurate it was the only practicable means of securing data on this point and did show roughly the condition of the steam. In most cases the steam was found to be saturated, although occasionally a test would show some priming and at times slight superheating. Therefore, in estimating later the amount of heat used in warming the buildings the steam was assumed to have been dry and saturated throughout the tests.

33 The condensed steam was weighed in two barrels, the return drips being piped into a trap which discharged into either barrel as desired. Each barrel was provided with a cover in order to prevent evaporation and to keep the conditions more uniform. While one barrel was filling, the other was emptied and weighed, this giving the tare, which every time was deducted from the weight of the barrel full. The exact time taken to fill the barrels was also noted thus permitting an estimate of the apparent rate at which the steam was condensed, that is, pounds per hour.

34 In addition to the above, temperature readings were taken about every four hours in different parts of the buildings. Outside temperature and weather conditions were also noted. From these readings curves have been plotted, Figs. 11, 12, 13 and 14 showing graphically the results obtained.

35 At the bottom of each of these cuts is given a curve showing the British thermal units per hour used in heating the buildings. This curve was plotted as follows:

From the Tables of Saturated Steam by Cecil H. Peabody the Total Heat in B. t. u. of the steam at the pressure at which it entered the heating system was found; also, the heat of the liquid in B. t.u. corresponding to the temperature of the returned condensed steam. The heat of the liquid was then subtracted from the total heat, giving the amount of heat in B. t. u. used in warming the store house, per pound of steam. Multiplying this by the number of pounds of condensed steam per hour, gave the total number of heat in B. t. u. per hour consumed in the store house, as plotted.

36 During the tests the store houses were used in the usual way, and the steam was turned on and shut off by the mill employés as they had been accustomed to do, so that as far as the use of the buildings was concerned the conditions during the tests were in no way special and, therefore, were representative of the average service. At the Bates store house the preliminary tests showed that the buildings

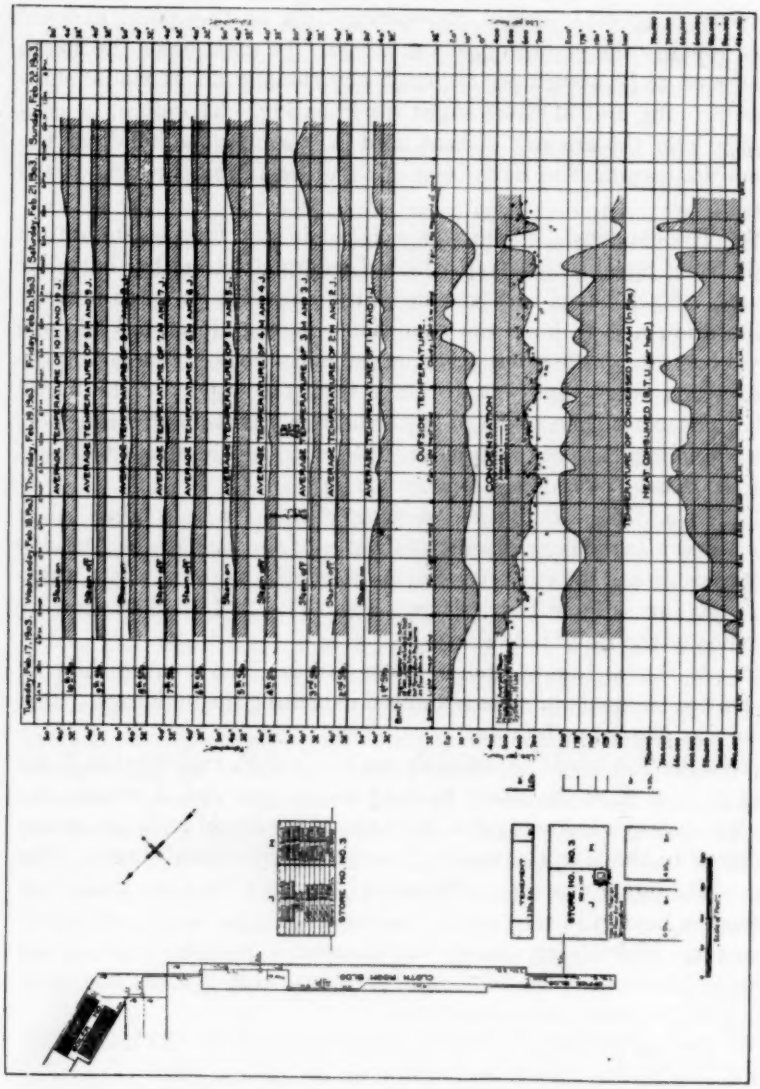


FIG. 11 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION, HAMILTON MFG. CO.

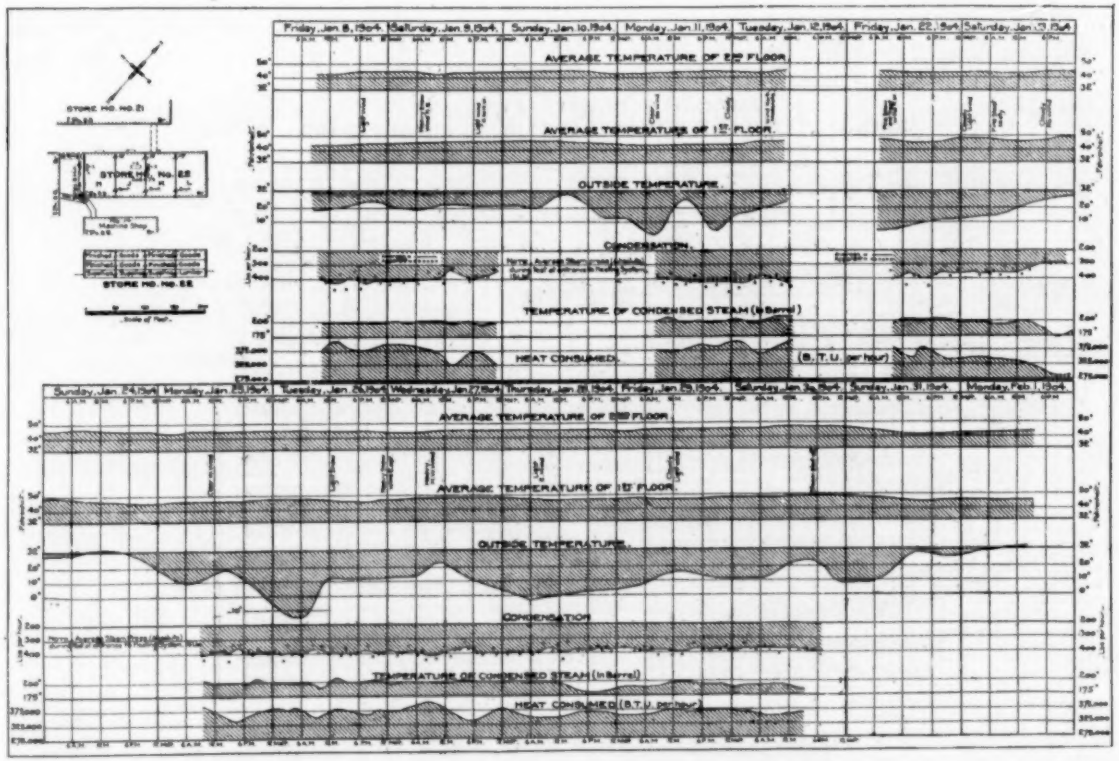


FIG. 12. CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION, LEWISTON BLEACHERY AND DYE WORKS

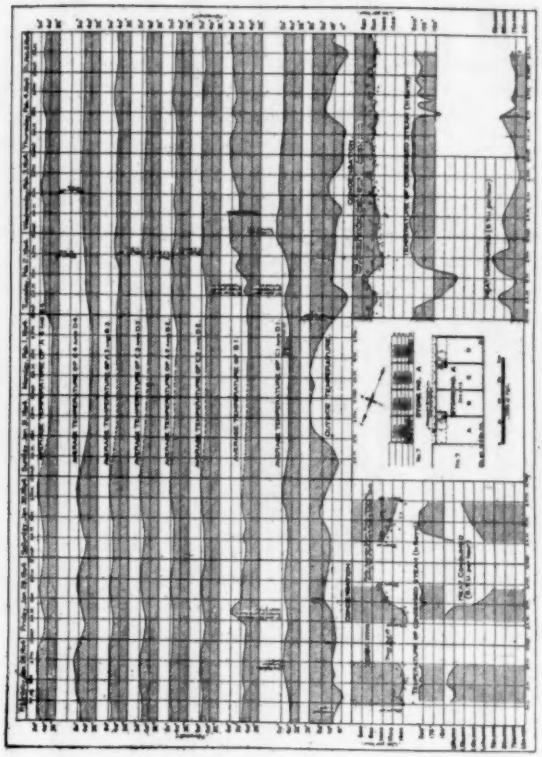


FIG. 13 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION, BATES MANUFACTURING COMPANY

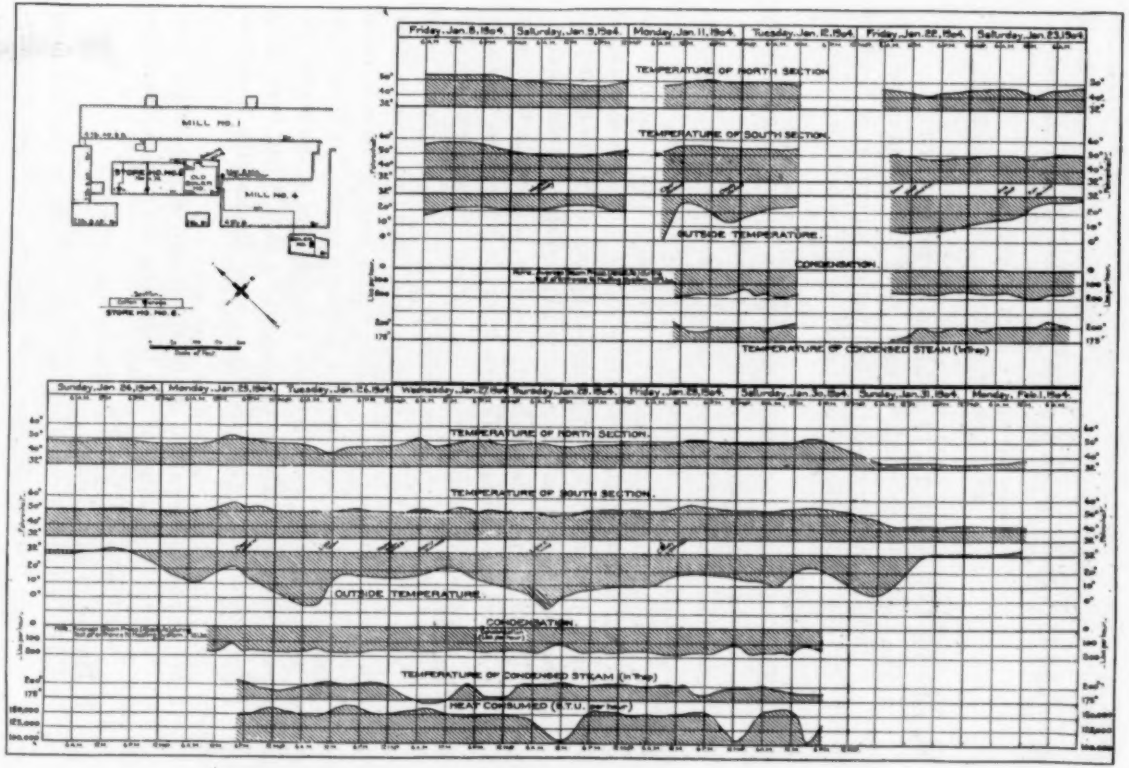


FIG. 14 CURVES SHOWING TEMPERATURES STEAM AND HEAT CONSUMPTION, ANDROSCOGGIN MILLS

were being kept at an unnecessarily high temperature, and a correspondingly excessive amount of steam was being used. In the final tests at this store house the steam pressure was reduced, as previously mentioned with a view to keeping the temperature, say, between 40 degrees and 45 degrees, which practice was followed after the tests.

RESULTS OF TESTS

By referring to Figs. 11, 12, 13 and 14, it is evident that:

a The temperature inside of each store house was quite uniform in the upper stories, but varied somewhat in the first story, due to the frequent opening of the outside doors for shipping.

b The variation in the steam consumption corresponded roughly to the changes in the outside temperature.

37 Throughout three of the tests, namely, the Hamilton, Lewiston Bleachery, and the Bates, a peculiar action of the steam traps was noted, viz: the frequency of discharge varied widely and at more or less equal intervals, although the conditions in the store house changed only gradually, thus giving a very irregular apparent rate of condensation as shown on the curves. The points plotted show at each weighing of the barrel the pounds per hour, based on the length of time in which the barrel was filling. The irregular discharge was probably due to the traps not entirely freeing the system of water at each discharge, so that it gradually accumulated in the basement piping until the slight increase in head on the traps caused them to discharge more often, with the results mentioned. This would seem to be confirmed also by the curve of "temperature of condensed steam," in that while the traps were operating less often, the temperature of the water discharged was correspondingly lower, suggesting that it had been lying in the pipes longer than when the traps were discharging more frequently.

c While the temperature of the condensed steam varied considerably in some of the tests, the average temperature was about 200 degrees F.

d Hamilton store house:

1 The maximum variation of temperature in the first floor was from 32 degrees to 50 degrees, the lower temperature being only for a short time, apparently coincident with the opening of the large outside doors for shipping. In the upper floors, the temperature varied from 34 degrees to 51 degrees, the higher temperature occurring

several hours after a sudden rise of temperature out of doors.

2 The effect of cracks through the floors is clearly shown, in that alternate floors could be kept sufficiently warm without steam in those floors, although the temperatures were uniformly a few degrees lower in those floors than where the steam was in the pipes.

e Lewiston Bleachery store house:

1 The maximum variation of temperature in the entire store house was from 37 degrees to 59 degrees.

These extremes do not show on the curve since only the average readings of a number of thermometers throughout the buildings are plotted.

f Bates store house:

1 The maximum variation of temperature in the first floor was from 45 degrees to 64 degrees; and on the upper floor 37 degrees to 58 degrees.

2 With the store house tightly closed, as during the night and on Sunday, the building cooled very slowly. Therefore it had been the practice to keep the steam shut off during these times, but of course keeping watch of the inside temperature. The tests also show that the store house required several hours with the steam on to regain its normal condition.

3 With about 10 pounds steam pressure in the heating system night and day, the average temperature throughout the store house was substantially the same as when the steam was in the pipes during the day time only,—that is, from 6 A. M., to 6 P. M. but at 60 pounds pressure. It is also of special interest to note that under these conditions, the steam consumption per 24 hours was about 35 per cent greater with 60 pounds steam pressure during the days than with 10 pounds continually.

g Androscoggin store house:

1 The rate of condensation in the heating system was quite uniform, notwithstanding the considerable variation of outside temperature and a comparatively uniform temperature in the building.

Table 2 gives a summary of the inside and outside temperatures and the cost of heating for the period during which store houses were under test.

TABLE 2

Items	Hamilton Mfg. Co. St. H. No. 3	Lewiston Bl. & Dye Wks. St. H. No. 22	Bates Mfg. Co St. H. "A"	Androscoggin Mills St. H. No. 6
Date of Test	1903 Feb. 17, a.m to Feb. 21, m.	1904 Jan. 25, p.m to Jan. 30, p.m.	1904 Feb. 2, a.m. to Feb. 5, m.	1904 Jan. 25, p.m. to Jan. 30, p.m.
Temperature (Degrees F.)				
Outside				
Average	12	14	7	14
Maximum	32	24	18	24
Minimum	1	−14	−4	−6
Inside (exc. warm basements)				
Average	41	47	48	49
Maximum	51	59	64	56
Minimum	32	37	43	41
Difference between average inside and outside	29	33	41	35
Average outside for coldest 24 consecutive hours during test	8	3	6½	6
Average inside for same period	40	46	47	49
Steam used				
Total consumption, pounds	56,929	49,282	70,096	20,007
Av. consumption per hr. pounds	612	380	815	156
Average consumption per 24 hrs. pounds	14,688	9,120	19,560	3,744
Av. consumption per 24 hrs. per 1000 cu. ft. of contents, pounds	8.06	14.2	14.8	25.1
Cost of heating				
Estimated first cost of steam pipe installed inc. trap and reducing valve, also 21¼ inch gates for each floor of each section. (30 cents per sq. ft. of heating surface)	$900	$210	$1120	$95
Same per 1000 cu. ft.	$0.555	$0.325	$1.19	$0.634
Cost of steam to heat st. h. per 24 hrs (assume 8 pounds of water evaporated per pound of coal, from and at 212 F., price of coal $4.25 per 2000 pounds)	$3.90	$2.42	$5.20	$0.99
Cost of steam per 24 hours per 1000 cu. ft. of st. h.	$0.0024	$0.0037	$0.0055	$0.0066
No. cu. ft. of st. h. heated per lb. of coal per 24 hrs.	884	566	385	319
Average cost of steam per 24 hours per 1000 cu. ft. of storehouse for the above three brick buildings is $0.00386.				

38 In order to determine the number of days of winter at Lowell and Lewiston during which the temperature is appreciably below freezing, the U. S. Government Weather Bureau reports for these

cities were obtained for three consecutive years, and the maximum and minimum readings for each day of the winter months have been plotted and the readings for three seasons have been averaged. Similar charts have also been made from the Weather Bureau reports at the nearest Government station the unheated store houses tested in the winter of 1901–1902, and also for a number of cities in the South, thus giving a general idea of the winter temperatures over a wide section of the country. The daily readings are plotted on Figs. 15 and 16, and the average temperatures for the three years for the winter months at these different localities are given in Table 3 following:

TABLE 3 AVERAGE TEMPERATURE OUT OF DOORS FOR THREE YEARS

November, 1901, to March, 1904
Taken from U. S. Government Records

Location	November 15–30		December		January		February		March 1–15		Average for Dec. Jan. and Feb.		Max. & Min.
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
Gardiner, Me.	39	22	32	11	27	4	31	8	42	22	30	8	19.0
Lewiston, Me.	37	23	32	13	26	5	30	9	42	22	29	9	19.0
Nashua, N. H.	40	23	34	14	29	11	32	12	43	24	32	12	22.0
Avon, N. Y.	39	25	33	16	30	13	29	13	43	25	31	14	22.5
Albany, N. Y.	38	27	33	16	29	13	31	15	42	26	31	15	23.0
Lowell, Mass.	42	26	36	17	33	13	35	16	47	27	35	15	25.0
Worcester, Mass.	40	27	34	19	30	15	33	17	45	28	32	17	24.5
New Bedford, Mass	43	29	38	22	34	17	35	19	44	28	36	19	27.5
Baltimore, Md.	46	35	41	28	37	25	39	25	51	37	39	26	32.5
Cincinnati, O.	45	33	38	23	38	22	38	22	52	37	38	22	30.0
Richmond, Va.	57	40	47	29	44	28	45	29	58	40	45	29	37.0
Knoxville, Tenn.	49	33	45	28	45	28	48	30	60	41	46	29	37.5
Charlotte, N. C.	53	37	48	32	46	31	49	33	61	43	48	32	40.0
Columbia, S. C.	58	40	54	36	50	34	54	37	65	47	53	36	44.5
Atlanta, Ga.	53	38	49	33	48	33	50	35	60	45	49	34	41.5
Montgomery, Ala.	59	40	55	36	55	37	58	40	68	51	56	38	47.0

39 On these charts for Lowell and Lewiston, the period during which the storehouses were under test is shown by double cross hatching. From these charts it is estimated that in Lowell, an average winter, including only that time during which the temperature is appreciably below 32 F., would be represented by 40 days similar to those during which the test was made at the Hamilton storehouse, and at Lewiston by 55 days similar to those during which the test was made at the Bates Manufacturing Company, and by 60 days similar to those during which the tests were made at the Lewiston Bleachery and Androscoggin Mills. Therefore, multiplying the cost per 24 hours

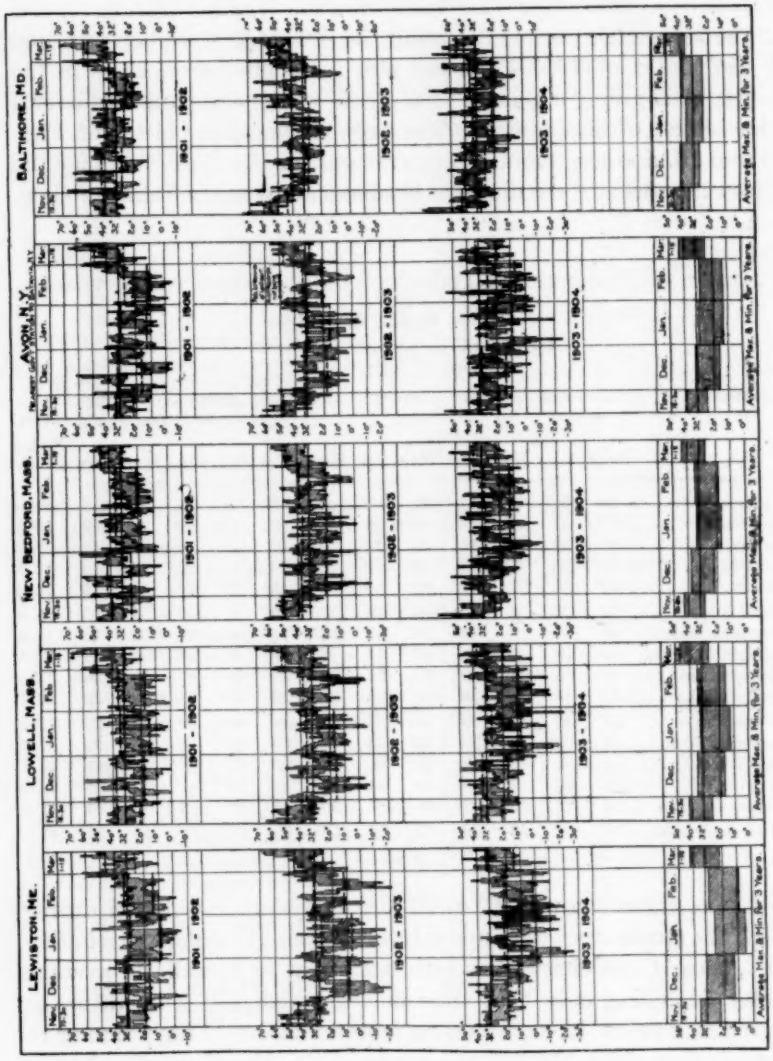


FIG. 15 TEMPERATURE RECORDS IN VARIOUS CITIES

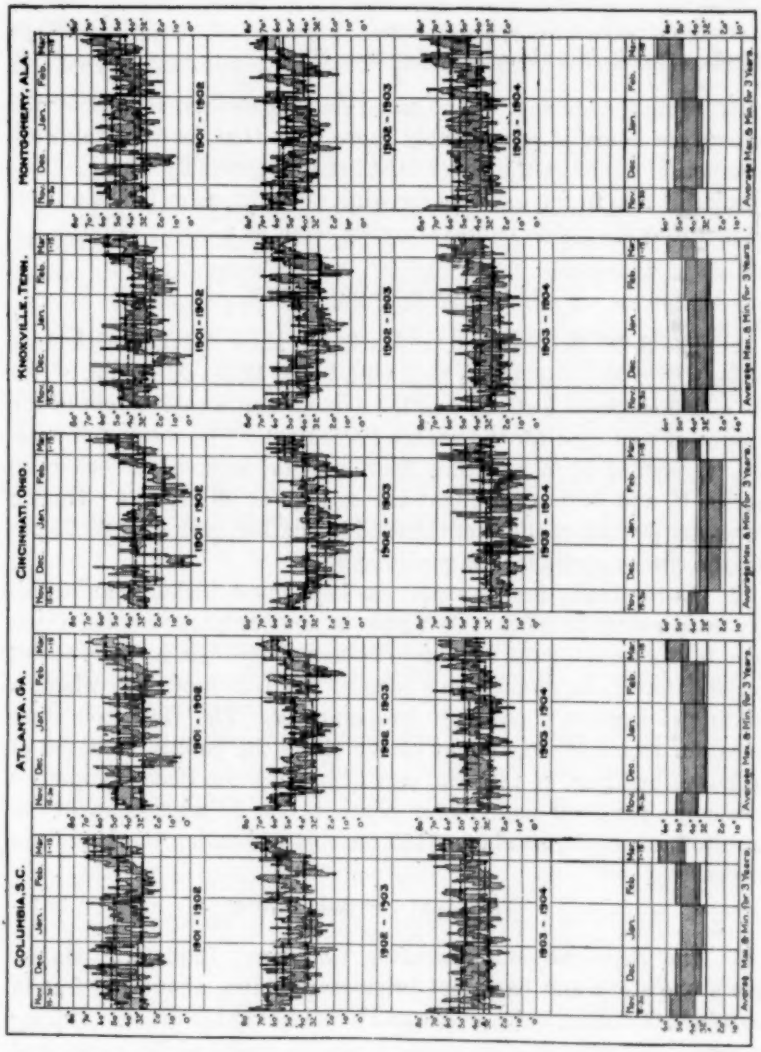


FIG. 16 TEMPERATURE RECORDS IN VARIOUS CITIES

obtained from the tests by the above constants, would give the cost for heating these four store houses per winter, as follows:

Hamilton Mfg. Co., No. 3 store house, Lowell, Mass.	$156.00
Lewiston Bleachery & Dye Works, store house No. 22, Lewiston, Me.	145.20
Bates Mfg. Co., store house A, Lewiston, Me	286.00
Androscoggin Mills, No. 6 storehouse, Lewiston, Me.	59.40

40 From the above it will be noted that the estimated costs for the Bates store house is considerably more than that for the Hamilton store house, although the latter building is appreciably larger. This is probably due to the more severe winter conditions in Lewiston and the fact that the inside temperature was kept at a higher point.

S. H. HOWE STORE HOUSE

41 The S. H. Howe Shoe Co., Marlboro, Mass., have a brick store house, 100′ x 60′, two stories high with boiler house adjoining. This was equipped with a steam heating system and a record kept of the amount of coal used for the winter 1901–1902. The inside temperature, registered by a recording thermometer, seldom got below 60 degrees F. and during the night ran as high as 90 degrees. During the winter 89 tons of coal were burned in heating, giving, at $4.25 per ton, the cost of steam for the winter as $378.

42 As the inside temperature was kept much higher than necessary to prevent freezing, this figure is not comparable with those given in the tests for the four store houses above. It is, however, of special interest, as giving some idea of the increased cost where a building is kept at these high temperatures. The Hamilton store house, for example, was about eleven times the cubical contents of the Howe building, so that the cost of heating the Shoe Company's store house per 1000 cubic feet of contents was 26 times that for the Hamilton, assuming as above $156 for cost of heating the Hamilton per year.

PEPPERELL STORE HOUSE

43 The Pepperell Manufacturing Company, Biddeford, Maine, have a one story and basement brick store house, about 150 feet in length and 60 feet in width at one end by 20 feet at the other. During the winter of 1904–1905 they kept a careful record of the amount of steam used in heating by weighing the return water, and estimated that 13 tons of coal were required for the season to keep the temperature in the store house between about 40 to 45 degrees F. This would make the cost, at $4.25 per ton, $55. This building has a

cubical content of 97,000 cubic feet, so that store house A of the Bates Mfg. Co., was about 9½ times as large. On a basis of $286 per year to heat the Bates store house, the cost to heat the Pepperell store house per 1000 cubic feet is nearly twice as much. This may be explained in part by the fact that the Pepperell store house was much smaller and the ratio of roof and wall area to cubical contents considerably greater than at the Bates.

ESTIMATED B. T. U., USING GERMAN FORMULAE

44 Having obtained definite information regarding the amount of heat necessary to keep these store houses at the desired temperature, it has been of interest to apply the formulae mentioned in the first part of the paper and compare the actual with the estimated cost. The heat required for each of the four store houses under the conditions of the tests (see Tables 1 and 2) has therefore been estimated using formula $H = k\ (t_1 - t_0)\ S$ and constants as clearly described by Professor J. H. Kinealy, Washington University, St. Louis, in a useful little book entitled "Formulae and Tables for Heating," in which are briefly given the results of careful experiments and the study of the subject by well known German investigators.

$$H = k\ (t_1 - t_0)\ S$$

H = British thermal units per hour. k = constant, value being as given in "Formulae and Tables for Heating." t_1 = average inside temperature. t_0 = average outside temperature. S = area of cooling surface in square feet.

45 Applying this formula to the store houses in question gives results shown in Table 3 following, where are also given for purposes of comparison the figures obtained from the tests.

TABLE 4

Store House	B.t.u. per hr.		Per cent difference
	by Formula	by Test	
Hamilton Mfg. Co., st. h. No. 3	620,000	626,000	0.97
Lewiston Bleachery, st. h. No. 22	373,000	369,000	−1.6
Bates Mfg. Co. st. h. "A"	682,000	800,000	17.3
Androscoggin Mills, st. h. No. 6	151,000	148,000	−2.0

46 In the case of the Hamilton and Bates store houses the figures given by the formula were increased 10 per cent on account of exposure and for the Bates store house a further increase of 5 per cent

was made because of the unusually high wind which prevailed during a considerable part of the test.

47 Table 4 is of special interest as showing how accurately the required heat may be calculated, and the author finds peculiar satisfaction in this close check between the estimated and actual results, believing that the work here described will still further increase the confidence of engineers in the results obtained from using the formula and constants mentioned.

48 In the case of the Bates store house it may be that the outside shipping doors were open more of the time than was noticed so that a special allowance for this should have been made when applying the formula. If so, this would account for at least a part of the difference between the estimated and actual results.

COST OF DRY-PIPE SPRINKLER SYSTEMS

49 If instead of heating the four store houses where special tests were made, automatic dry-pipe valves had been provided in addition to the sprinkler equipment which would be necessary if the store houses, were warmed, the first cost of such dry-pipe valves, valve houses and attachments would have been about as follows, and for easy comparison the first cost of all the heating pipes is also given:

FIRST COST

	Dry-pipe. Equipment	Steam Heating Equipment
Hamilton Mfg. Co., store house No. 3	$2580	$900
Lewiston Bleachery and Dye Works, store house No. 22	680	210
Bates Mfg. Co., store house A	1360	1120
Androscoggin Mills, store house No. 6	310	95

50 With a good dry-pipe equipment, the annual cost for care and repairs to the dry-pipe valve and attachments would be small and would ordinarily add little to the yearly pay roll. With steam heat considerable care will be necessary to prevent freezing on the one hand and over heating on the other, and if not given, the waste in steam, due to over heating, will quickly exceed the cost of maintenance of a "dry" system. It is difficult to make exact figures, but it is believed in general that the cost of maintaining a "dry" system would be less than the cost of properly taking care of a store house heating system, and that the totals are not large in comparison with other factors, so that this point need not be seriously considered.

CONCLUSIONS ON HEATING VERSUS A DRY-PIPE EQUIPMENT

51 The data show that the first cost of steam heating pipes would ordinarily be less than the first cost of a dry-pipe valve equipment; also that it will cost more yearly to heat a store house than to take care of its sprinkler system with a dry-pipe valve, but that this cost, even in our colder sections, is a small matter compared with many other expenses for maintenance and operation. In warmer sections, the yearly cost of steam would be small and would become an unimportant item. In brief, while heating costs a little more, the extra expense generally would be negligible.

52 Tightness of walls and windows, meaning ability to keep out cold winds, has a large effect on inside temperatures and the cost of heating. In the Southern States no heating would be necessary ordinarily in well built store houses of brick and probably of wood if some special care were taken to make the walls non-conducting and tight, and it is probable that a moderate amount of mason and carpenter work in stopping cracks and making doors and windows fit more tightly would make heating unnecessary in many store houses in these warmer sections.

CALCIUM CHLORID

53 Some attention has been given to the possibility of filling sprinkler pipes in cold buildings with a non-freezing liquid, and calcium chlorid has been suggested for this purpose on account of its several good properties and its low cost. The following somewhat general statements may be made in regard to it.

54 Calcium chlorid ($CaCl_2$) comes in solid or liquid form, and when properly made is absolutely neutral; that is, neither acid nor alkaline. The freezing point of the liquid varies with the strength of the solution and can readily be made, so that it will not freeze at temperatures 30 degrees below 0 degrees F. The coefficient of expansion is greater than water for ordinary temperatures. A solution freezing at 0 degrees would be 1.175 times heavier than an equal volume of water.

55 A chlorid solution has great affinity for water, so that an open pail of it will increase a little in volume in damp weather and decrease when the weather is dry, but will stay at about the same level all the time, thus making it very useful for fire pails.

56 On account of this property, however, articles wet with it will not readily dry, but if washed with water the cholorid will quickly disappear. Cotton, wool, and textiles, if wet with it, would probably have to be washed to remove the chlorid before they would dry, and

the exact effect of this in affecting salvage is a matter needing further study.

57 In a few cases calcium chlorid has already been used in the sprinkler systems, approximately as follows. In the main pipe supplying the sprinklers is provided a check valve located beyond danger from freezing, with a gate valve above it for draining the system. The gate in the main pipe is closed and the sprinkler system drained. The system is then pumped full of the chlorid solution, and, in order to surely keep the check valve closed and prevent loss of the solution, the pressure in the sprinkler system is raised a few pounds above the normal pressure in the outside supply pipe. The main gate is then opened. It may be necessary to provide small air-pressure tanks for expansion, and occasionally to pump in additional chlorid to make up for waste.

58 The point has been raised that when used in this way, if the check valve separating the chlorid from the public water should leak, the chlorid solution would get into the public supply. It is believed, however, that any ordinary leakage would be small and would quickly become so diluted that unless a drinking water tap were very near the check valve, the condition would not be noticed. Calcium chlorid is, moreover, a somewhat common impurity and not deleterious unless in considerable quantities. It is therefore believed that there would not be great difficulty in providing check valves for such work through which there would be little, if any, leakage. As a special precaution, a check valve with two seats and the intermediate space open to the air could be used, but with such a valve care would be necessary that the differential action shall not be sufficient with low pressure water supplies to allow the column effect of the chlorid solution in the pipes to overbalance the water at ordinary pressure, thus preventing the opening of the valve in case of need.

59 Chlorid solutions in such quantities as would be used in store houses can probably be obtained at an average cost of about 2 cents per gallon, and on this basis the cost for filling the sprinkler equipment in the four store houses where the heating tests were made would be as follows:

Hamilton	abt. 2220 sprinklers	requiring abt. 2500 gals. $CaCl_2$	costing abt.	$50
Lewiston	abt. 600 sprinklers	requiring abt. 680 gals. $CaCl_2$	costing abt.	14
Bates,	abt. 1600 sprinklers	requiring abt. 1800 gals. $CaCl_2$	osting abt.	36
Androscoggin	abt. 130 sprinklers	requiring abt. 150 gals. $CaCl_2$	costing abt.	3

60 Calcium chlorid is shipped in liquid form in tank cars holding about 4500 gallons, the strength being such that an equal volume of

water can be added and still get a solution freezing at something below 0 degree F. It is also shipped in solid form in iron drums weighing something over 600 pounds. One drum will make about 250 gallons of 0 degrees solution. The freezing point of a solution can easily be determined from its specific gravity.

61 The following table gives the quantity of "Solvay" fused or solid calcium chlorid required to make solutions of given specific gravities and corresponding freezing points, viz:

Specific gravity	Per cu. ft. solution	Per gal. solution	Freezing point
1.250	28.06 pounds	3.76 pounds	−32.6°F.
1.225	25.06	3.36	−19.5
1.200	22.05	2.95	− 8.7
1.175	19.15	2.56	zero
1.150	16.26	2.18	+ 7.5
1.125	13.47	1.80	+13.3
1.100	10.70	1.43	+18.5

62 If used in a sprinkler equipment, it would be necessary to have enough chlorid on hand, in either liquid or solid form, for one, or better for two or three re-fillings, so that after a fire or a sprinkler break the system could be quickly put again into commission. The solid form can be stored indefinitely in drums, if kept hermetically sealed. It would be necessary to have a tank with each sprinkler system so that the solution could be saved whenever it is desirable to drain the system for changes or repairs.

CONCLUSION

63 Compared with dry-pipe valves, calcium chlorid would give all the advantages which come from a "wet" sprinkler equipment; less apparatus would be required; no sub-division of the equipment into 300 or 400 head groups would be needed, as is required with dry-pipe work; and the first cost would ordinarily be less. Again, the danger of accidental freezing due to imperfect draining or to some difficulty with steam pipes would be eliminated. A system filled with chlorid would probably require about the same amount of weekly care as a dry-pipe system.

64 The objections to calcium chlorid would be its cost, if there were frequent fires or breaks in the sprinkler system; probably greater water damage on some classes of materials, especially machinery and the difficulty of making sure that protected properties would always have a sufficient extra supply of chlorid on hand so that after

a fire or a sprinkler break there would not be much delay in getting the system again in service.

65 Finally, with the evidence at hand, it seems probable that calcium chlorid can be used in some places to advantage, and there is at least a possibility that further investigation and experience may show it desirable in an even larger field.

SPECIAL AUTO STEEL

By THOS. J. FAY, NEW YORK
Non Member

The introduction to this subject is necessarily abridged owing to lack of time and space, and with a view of presenting all the useful information the matter of auto steel will be taken up at once.

2 Attention is called to Tables 1, 2, 3, and 4, in which the data of the various grades of steel are set down. The reliability of all these tests is shown in that the steel was purchased, tested, machined, put into service, and the results of service were noted in nearly every case by the author. In some of the cases where the products were found in service the degree of satisfaction was noted and tests were made after service.

3 At all events the steel mill had nothing to do with the tests. The service was regular automobile work of the most exacting order in high priced, high powered cars, excepting in one or two instances. It is the firm belief of the author that tests of steel to be of value should include the service test.

4 Before entering into a detailed discussion of the relative value of the several products, it may be well to set forth the results:

a Carbon steel for crank shafts, gears, axles, distance rods, and springs, as well as some of the less responsible parts, showed many failures in service.

b Not a single part made of chrome nickel steel ever used by the author failed in service, although some of the chrome nickel steel was not up to the high standard of quality.

c Puddle iron for mud guards, lamp brackets, and like parts is a superior product; moreover, carbon steel does not render so efficient service.

d So called puddle steel, steel below 0.10 per cent carbon, as usually produced, does not serve as a good substitute for the fine grades of iron mentioned above.

To be presented at the Indianapolis Meeting (May, 1907) of The American Society of Mechanical Engineers and to form part of Volume 28 of the Transactions.

e Die forgings of alloy steel make the use of alloy steel quite possible for even low priced cars.

f Designs must take into account the fact that alloy steel is to be used, or the cost of machining will be excessive.

5 Mechanical engineers are as a rule fully alive to the fact that in fashioning even ordinary steel into the shape to make a servile device, the steel will lend itself to the process more or less readily depending upon the carbides contained in the product. The influences can be stated briefly as follows:

a Carbon under 0.16 per cent is below the point at which steel will harden noticeably upon subjection to heat and then cooling in oil or water.

b While sulphur can be as high as 0.10 per cent in mild steel for cold working, it is a fact that the presence of carbon, chromium, and nickel demands a decided reduction in the sulphur content.

c Phosphorus is not desirable in steel for important service, but ordinary bessemer products do contain phosphorus up to 0.10 per cent, and this kind of steel serves for many useful purposes. Phosphorus very far below this stated amount would render alloy steel useless.

d Silicon can vary considerably in ordinary steel, but its presence in alloy steel is detrimental and should be limited.

e The percentage of manganese is often run up in ordinary steel to compensate for a low percentage of carbon, the object being to satisfy the specifications for physical properties. In alloy steel this "doctoring" process is not practicable.

f Nickel in nickel steel has well defined and useful ranges, but its relation to carbon must be closely maintained.

g Chromium has a marked effect upon the properties of steel and with the known mixtures can range as low as 0.50 per cent and as high as 3.50 per cent, but the relation of both carbon and nickel must be maintained within narrow limits.

h Vanadium as an intensifier is even more pronounced than chromium, but both chromium and nickel can be present if the quantities are properly regulated.

i Wolfram is a peculiar intensifier and changes the character of the steel by changing the carbon relation.

j Copper until recently was considered as of little or no value, but is now used in the finest grades of ball bearing steel, and is often found in "fire box steel."

6 Other elements, as boron, uranium, titanium, platinum, and other possible alloying metals will not be discussed because their uses are not defined. Later research may develop more satisfactory results than are now obtainable.

7 Having thus set down the composition of steel products that are used more or less advantageously and knowing their results, the next important consideration is to fix the limits of the undesirable carbides.

PHOSPHORUS

Ordinary bessemer steel, between	0.08	and 0.10
Ordinary structural steel, between	0.06	and 0.08
Specification structural steel, between	0.04	and 0.06
Inferior alloy steel, between	0.02	and 0.04
Good alloy steel, between	0.015	and 0.02
Superior alloy steel, between	0.010	and 0.015

SULPHUR

Ordinary bessemer steel, between	0.08	and 0.10
Ordinary siemens steel, between	0.06	and 0.08
Ordinary structural steel, between	0.04	and 0.06
Good boiler plates, inferior alloy steel	0.02	and 0.04
Good alloy steel, between	0.015	and 0.02
Superior alloy steel, between	0.010	and 0.015

SILICON

Superior alloy steel, between	0.10	and 0.20
Good alloy steel, between	0.20	and 0.30
Inferior alloy steel, between	0.30	and 0.40

MANGANESE

Very soft alloy steel, between	0.10	and 0.20
Very soft alloy steel, between	0.20	and 0.30
Soft to medium alloy steel, between	0.30	and 0.40
Medium alloy steel, between	0.40	and 0.50
Fairly hard alloy steel, between	0.50	and 0.60
Hard alloy steel, between	0.60	and 0.70

8 The range of all these carbides is quite a different matter from the consideration of the range of the intensifier, unless it be said that manganese plays a small part, although the results with low manganese are more satisfactory on the whole than when manganese is used as an intensifier.

9 Taking up the intensifiers in detail, it can be safely said that carbon becomes a very disconcerting element, unless held within narrow limits.

RELATIONS OF NICKEL TO OTHER METALS

Nickel		Chromium		Vanadium		Manganese		Carbon	
from	to	from	to	from	to	from	to	from	to
2.00	2.50	0.60	0.70					0.30	0.40
3.00	3.50	1.40	1.60					0.25	0.30
4.50	6.00	1.50	1.70					0.20	0.25
10.00	12.00	1.75	2.25					0.40	0.50
22.00	26.00	2.25	3.25					0.50	0.60
30.00	32.00							0.50	0.60
22.00	26.00							0.40	0.50
10.00	12.00							0.30	0.40
4.50	6.00							0.25	0.30
2.50	3.50							0.22	0.28
1.00	1.50							0.20	0.25
2.50	3.50			0.25	0.30			0.20	0.25
1.15	1.50	1.00	1.30			0.90	1.10	0.20	0.25
		1.40	1.60			0.90	1.10	0.20	0.30

10 That the ranges it is possible to employ may be by far greater than these values is scarcely to be doubted, but beyond the limits defined by experience the question becomes purely academic. It is the aim in this paper to consider things from the point of view of the executive engineer.

11 It will be observed that nickel appears in almost every mixture of alloy steel except one, viz: Table 4, No. 42. This is a chrome wolfram product, the peculiarity of which lies in the fact that 0.10 per cent copper is found in its analysis. Incidentally the steel is a fine product.

12 Nickel then is of the utmost importance in alloy steel, but nickel without chromium, or chromium and vanadium, is very inferior in comparison with the more complex alloys. While it may be true that nickel alone checks the segregation and acts on the cementing materials so as to bind the elements more closely, yet nickel not only fails to prevent blow holes, but they are more prevalent in nickel steel than in carbon steel.

13 The production of nickel steel even with greatest care and extraordinary skill, is attended by many vicissitudes, and users of this product are ever confronted by a possibility of hidden flaws. Nickel besides affecting the melting carbides, raises the elastic limit relation to the tensile strength, but in comparison with chrome nickel steel, the elevation of the elastic limit in nickel steel is not marked. Nickel also affords immunity from "extending cracks" but unfortunately *it is very apt to conceal them.*

14 Chromium combined with nickel is decidedly advantageous because the effect on the melting carbides or on the eutectic more

likely, is not in opposition to the effect of nickel, nor is the influence identical. It follows then that the carbides are more closely bound in this cementing relation when chromium is present, than can be the case if there is nickel and no chromium.

15 The relation of the elastic limit to the ultimate strength is vastly changed by the use of chromium; moreover, this change of relation is not at the expense of the elongation to any marked extent. But the presence in any considerable amount of some of the carbides, as silicon, sulphur, phosphorus, and manganese is to be deplored, for then the elongation is noticeably a diminished factor, and the ability of the product to withstand severe shock falls off in a most disconcerting way.

16 Vanadium seems to supplant nickel, and when combined with it reduces the need of chromium to some extent. This element influences the eutectic in its own way, besides supplanting nickel absolutely and chromium in part for certain grades of steel. The specific value of vanadium is due to the ability of this element to thwart constitutional segregation by combining with carbon rather than by altering the melting point of the carbides. This explains the added value when a small increment of vanadium is introduced in conjunction with nickel and chromium. Vanadium is also important because it tends to safety, in that "metal fag" is much deferred, and it is also found that steel containing vanadium, with or without nickel, is free from "crack and tension" tendencies. Moreover, vanadium steel is not so apt to have blow holes; although for that matter chrome nickel steel is free from such imperfections to a marked degree.

17 The carbon content must be controlled with vanadium to a greater extent than with either nickel or chromium, and an increase in vanadium should follow a decrease in carbon, otherwise the product might prove too hard to machine and have other faults. In this connection it might be well to point out the reasons why alloy steel is discriminated against:

a It costs more per pound than the carbon steel products;
b It resists machining on account of its tenacity.

18 The great problem in automobile engineering at the present time, is not to substitute for alloy steel or to experiment with all possible mixtures, but to find some one product that will serve for the purpose, which can be fashioned readily and quickly. The price of this product must be reasonable, but it does not have to compete with bessemer steel for two reasons, viz:

a Bessemer steel will not serve the purpose in any event.

b Alloy steel has fully four times the elastic limit and all the desirable advantages, though it should cost four times as much as bessemer steel.

19 Motor car tires should be built as light in weight as possible, and the pneumatic are the only ones that are satisfactory for touring cars and the degree of satisfaction they render may be expressed as follows:

TIRES

920 mm.	× 120 mm. tires
for 2000 pounds	= 100 per cent
for 3000 pounds	= 45 per cent
for 4000 pounds	= 25 per cent
for 6000 pounds	= 11 per cent
for 8000 pounds	= 6 per cent

20 The 920 x 120 tire is a standard touring car size and the figures of merit are relative approximations based on the assumption that a car is run an average of 25 miles per day, and is in service 200 days per year. This represents the average operation, $200 \times 25 = 5000$ miles, the life of the tires, if load is 2000 pounds. Of course, much depends upon circumstances, such as make of tires, speed of car, roads traversed, the chauffeur, etc., but relatively the above figures will be found correct.

21 If it costs $500, including extras, to equip a car with tires, and they are affected by weight as hereinbefore indicated, it is difficult to understand the economy in the use of inferior steel. This discussion does not involve small, light, low powered cars, although these have their own problems, but it is a separate subject, that can only cloud the issue, if introduced; however there is one other point that must be borne in mind.

22 The life of the tires must be reckoned on a constant speed basis; that is to say, if the speed of a car is increased, in proportion as the weight is decreased, instead of lasting longer, the tires will fag out sooner. To show the effect of speed on tires in absence of excessive weight it is only necessary to point out that the Crocker racing car wore out a set of tires in running 13 miles on the Empire City track. The car weighed one ton and broke what was then the world's record for time as long as the tires lasted. It is very evident that even great weight is less of a handicap than great speed, if tires are to be considered.

23 A motorist who can make 40 miles per hour in a 40 horse power 4000 pound car, should be satisfied with 40 miles per hour in a 20 horse power 2000 pound touring car, for the advantages of good steel

are then assured. When ordinary steel is used a 40 horse power car, with a body 2.50 meters in length and accommodating seven passengers, weighing 4000 pounds at least, will do no more than 40 miles per hour. On the other hand, a modern design of alloy steel using a 2.50 meter body can come within 2000 pounds and the factor of safety would be many times that of the heavier car of ordinary steel.

24 It may be well to indicate just what it means to reduce the weight of a car aside from the benefits to tires. This can be done by considering the fundamental formula of the energy stored in a body thus

$$E = \frac{WV^2}{2g} = \text{stored energy}$$

Hence for the respective cars:

$$E = \frac{4000 \times 58.66^2}{2 \times g} = 213{,}810$$

$$E = \frac{2000 \times 58.66^2}{2 \times g} = 106{,}905$$

25 But if the lighter car should travel 50 per cent faster: Then

$$E = \frac{4000 \times 58.66^2}{2 \times g} = 213{,}810$$

and

$$E = \frac{2000 \times 88^2}{2 \times g} = 240{,}497$$

showing that reducing the weight one half and increasing the speed 50 per cent, which is the average expectation, fixes the stored energy above that of the heavier car.

26 However, considering equal speeds it is better to build within the low weight limit and to use a 20 horse power motor, and for a grade a 2000 pound car with a 20 horse power motor is better than a 4000 pound car with a 40 horse power motor, because, while the power is doubled for double the draw bar pull, the level road resistance would be less for the lighter car, the same size of tires being used.

27 Attention is here called to the photographs, Figs. 1 to 10 inclusive, each one of which represents a feature of the steel problem, as it affects the automobile.

28 Illustrative of the advantageous qualities of chrome nickel steel, reference will be made to one particular application that proved to be specially profitable.

29 In the 40 foot racing boat "Dixie", constructed for Edward Russell Thomas in the shops of the Smith & Mabley Mfg. Co., during the author's time as chief engineer, the weight in pounds per horse power became an important question.

The motor was designed as follows:

Number of cylinders	8
Bore of cylinders	6½ inches
Stroke of piston	6¾ inches

Angular velocity of crank shaft, 900 revolutions per minute and

$$H\,P = \left(\frac{d^2\,l\,n\,s}{10^9}\right) \times 4$$

$$= \left(\frac{165^2 \times 8 \times 171 \times 900}{10^9}\right) \times 4 = 134$$

in which

d = bore of cylinder in millimeters;
l = stroke of piston in millimeters;
n = number of cylinders;
s = speed of crank shaft in revolutions per minute.

30 This motor developing 134 brake horse power, would have a torque as follows:

$$P = \frac{h\,p\,33{,}000}{2\,\pi\,R\,S}$$

R = one foot.

$$= \frac{134 \times 33{,}000}{6.28 \times 900} = 782.3 \text{ pounds at one foot radius.}$$

31 To handle this torque of 782.3 pounds, a shaft nearly 20 feet long, and 1¼ inches in diameter was employed; this has served nearly three years, showing that it was not too small for the work. This shaft was made by rolling a Krupp bar, 4 inches in diameter down to 1¼ inch in diameter, and instead of machining, the shaft was "planished" cold, so that it came about within 0.009 inch of the exact size. The bearings were *lignum vitæ* "free fit."

32 The physical properties of the shaft were as follows:

Tensile strength	158,000 pounds per square inch
Elastic limit	149,500 pounds per square inch
Elongation in 2 inches	12 per cent
Contraction	49.8 per cent

33 If the shaft had been of Tobin bronze, its diameter and its weight would have been very much more, as the following will show:

$$d = \sqrt[3]{\frac{P \times 1}{K}} = \text{diameter in inches}$$

$$\sqrt[3]{\frac{782.3 \times 12}{2500}} = 1.58 \text{ inch}$$

in which:

P = torsion in pounds;
1 = radius of torsion arm in inches;
K = a constant for Tobin bronze the ordinary material used for propeller shafts.

34 The margin of safety was actually the maximum for the alloy steel used, and the metal fatigue was much deferred. A further investigation will disclose the following:

$$J = \frac{\pi d^4}{32} = 0.23954;$$

$d^4 = .44$ inches;
$d = 1.25$ inches;
$c = \frac{1}{2}d = 0.625$ inch;
$S = 150{,}000$ pounds per square inch;

$$Pa = \frac{S\,J}{C} = 57{,}489.6;$$

$$d = \sqrt[3]{\frac{5.1\ Pa}{S}} = 1.250 \text{ nearly,}$$

in which

J = the polar moment of inertia of the section with respect to the axis;
C = distance of the most remote fiber from the axis;
S = unit shearing resistance in pounds per square inch;
P = pounds, at a distance, a, radius inches from the axis of the shaft so as to twist it;
d = diameter in inches, of the shaft given the value of 150,000 pounds per square inch extreme fiber tension.

35 Since the value $Pa = 57{,}489.6$ pounds, the relation of this to the torque of the motor will afford an idea as to the factor of safety, which is for the motor:

$782.3 \times 12 = 2387.6$ in Pa eqivalents on a static basis; but since the load is not static, nor of a shock value, the true approximate value may be taken as:

$$\frac{3387.6 \times 3}{2} = 3581.4$$

and

$$\frac{57,489.6}{3581.4} = 16.54$$

equals ratio of the maximum ability of the shaft to the maximum ability of the motor.

36 In so far as strength is concerned, the shaft could have been a little smaller, but there is one other point to be taken into account, *i.e.*,

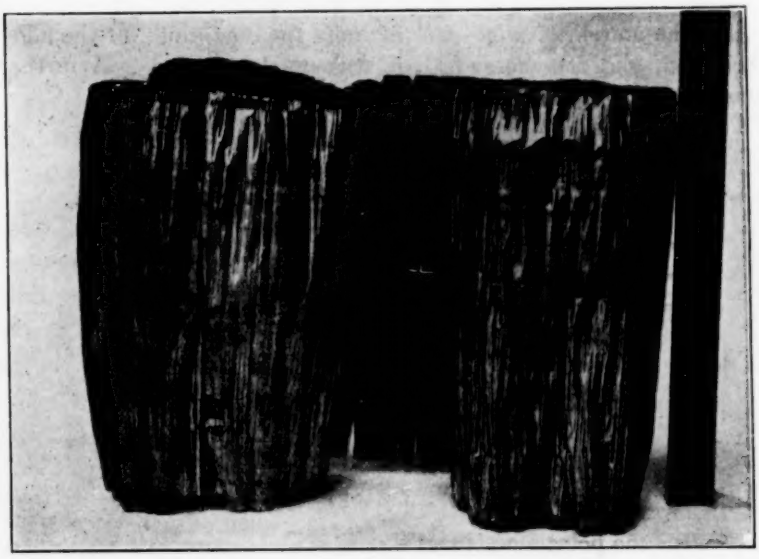


FIG. 1 L.B.R. KRUPP GUN STEEL
Turning 11 feet long
Turning 8½ feet wide
Turning 0.005 feet thick
Tensile strength, 70,000 lbs. per square inch

the twist on the shaft, between the two ends, would become sufficient with a fluctuating torque to cause a noticeable "stutter" of the hull in the water, and this continuous surge would reduce the speed of the boat, which was constructed under a guarantee of 30 miles per hour.

37 The twist of the shaft was not enough to communicate the "stutter" contemplated, but it was figured at 27 degrees 30 minutes and was believed that the equipment was reduced some 70 pounds in weight by the use of alloy steel.

38 The angle between the fixed and the free end based on the semi-shock equivalent of the motor torque would be as follows:

$$\theta = \frac{32 \times Pa \times L}{\pi d^4 G} = 0.48$$

arcs of one radiant each, in which the equivalent angle in degrees would be:

$$a = \frac{180 \times \theta}{\pi} = 27° 30'$$

and in which

$G = \frac{1}{3} \times E = 10{,}000{,}000$ assumed;
E = modulus of elasticity for tension =30,000,000, taken,
L = length of shaft in inches = 200, for diameter given.

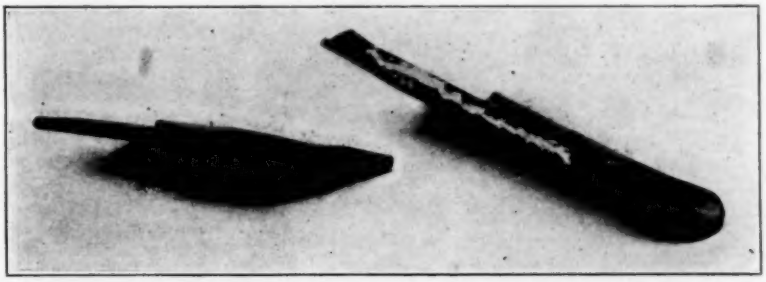


FIG. 2 FIG. 2a

SPECIMENS OF NICKEL STEEL SHOWING DIFFERENT RESULTS UNDER DIFFERENT TREATMENT

Width of cut, 8¼ inches.
Thickness of cut, 0.005 inches.
Length of specimen, 10½ feet.
Tensile strength of L.B.R. steel, 70,000 lbs. square inch.

39 This long unbroken length of a cut from a gun barrel as thin as it is, illustrates adequately the fact that steel with a high elongation and very low in the carbides can be machined readily and admits of taking cuts of great or small thickness depending upon the exigencies of the situation.

40 The photographs give two views of one specimen of this steel, one of which shows one half with a split developed by bending over the piece 180 degrees and hammering down flat, while the second picture shows the other half of the same specimen, bent over 180 degrees and hammered down flat, without developing a sign of a crack at all.

41 The difference is due to the fact that one half was annealed and the other was not. The pieces were made into the shape shown by flattening a 1¼ inch round bar down to a ¼ inch flat sheet, at a temperature of about 950 degrees C. under a steam hammer. The importance of annealing is apparent.

SPECIAL NICKEL STEEL

Special nickel steel subjected to heat treatment acts as follows:

a Heated to 900 degrees C. and reduced in diameter from 1¼ inch to 1 inch, allowed to cool, was found to be soft.

b Heated to 900 degrees C. quenched in water and found to be "file hard;"

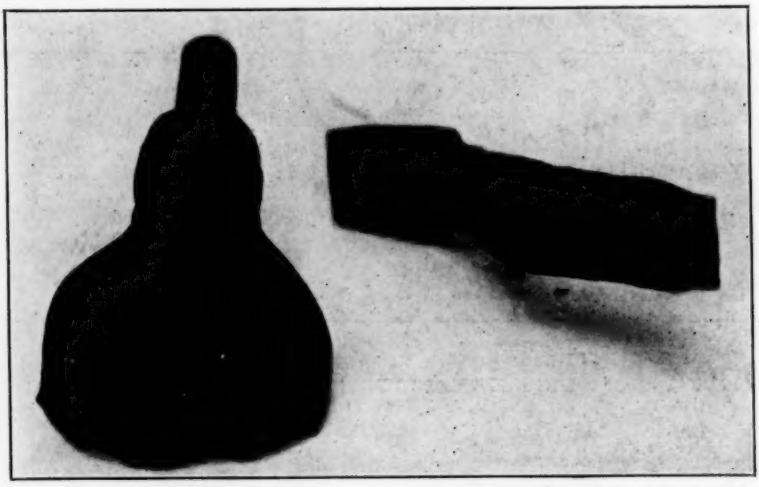


FIG. 3 FIG. 4

FIG. 3 FLATTENED OUT HOT TO SHOW FORGIBILITY DID NOT CRACK OR HARDEN
FIG. 4 CRYSTALLINE STRUCTURE AFTER FORGING

c Annealed at 570 degrees C. for one hour and rendered soft by the process;

d Heated to 900 degrees C. it can be flattened out to ¼ inch thickness without showing frayed edges.

42 It is hardly possible to repeat this process with any inferior alloy steel containing over 0.020 phosphorus, and 0.030 sulphur, high manganese, or carbon above 0.25 per cent.

43 Notwithstanding the fact that this carbon steel was a fine specification product, it fractured at a tool mark in the act of shaping, and the fracture showed a large crystalline structure. While it is

admitted that the forging process was not skillfully performed, this is a common occurrence with carbon steel containing above 0.15 per cent carbon, and this sort of a thing is not likely to follow the use of alloy steel.

44 This photograph shows a car, that was completely wrecked in a collision. A close examination failed to disclose even a crack in any "deformed" member of alloy steel although the wrecked car was three years old. The only broken members were of cast aluminum.

45 Other wrecks of carbon steel cars examined by the author invariably showed fractures of all or nearly all deformed members.

46 This product was taken from a built up crank shaft of

FIG. 5 60 H. P. MERCEDES RACING CAR
No broken parts of steel

E. F. 60-0 Krupp Steel in the Ellsworth Shop, under the direction of the author, using a 30 inch lathe specially fitted up to handle this work.

47 The data were as follows:

Mean diameter of work 8 inches, circumference 25.1328 inches.
Speed of spindle 48 revolutions per minute, hence

$$\frac{48 \times 25.1328}{12} = 100.53 \text{ feet per minute.}$$

The "Novo" steel tool held its own on this work for about four hours, but at a speed of 20 revolutions per minute of the spindle, it would not do the work satisfactorily.

48 Fig. 10 is offered to show the shape of tool that seems to do the most work without turning its edge or developing rupture.

49 The setting of the tool is of the utmost importance, and the tool post must be particularly rigid. As will be observed, the cutting edge intercepts the metal at a point 1–20 of the diameter of the work above the axle center. When the cutting edge intercepts the work near or below the center, trouble ensues.

50 Of the most important matters, the ability of the metal to *withstand shock loads without rupture is paramount* and an actual

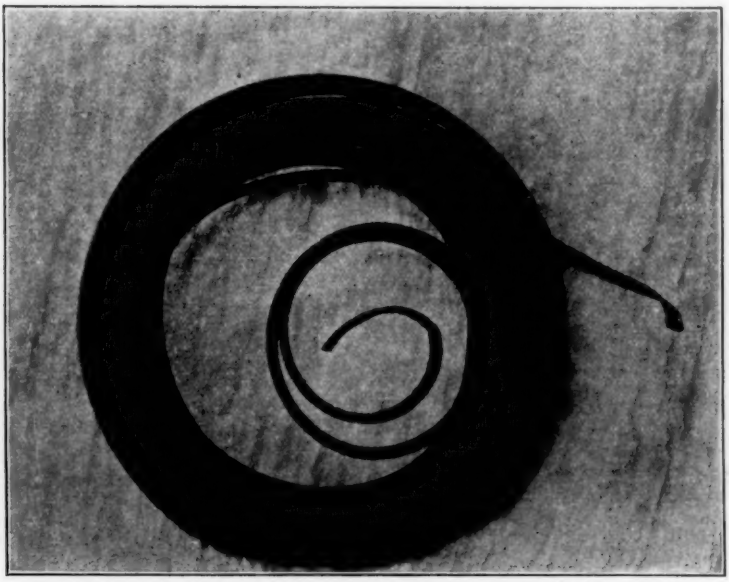


FIG. 6 CHROME NICKEL STEEL
From a 30" lathe at a red heat, $\frac{1}{4}$" x $\frac{3}{16}$" 100 ft. per min.
Relative hardness = 9.752
Relative usefulness = 5,158,500

collision should only result in the deformation of the parts, but without rupture. Fig. 5 of a 60 horse power Mercedes racing car was taken on the Vanderbilt course last fall, just after the car collided with a telegraph pole. The author examined every part without discovering a broken steel member, although not one was straight, and most of them were greatly distorted, as the photograph shows.

51 This car was of alloy steel in the following principal parts:

Crank shaft	E. F. 60–0	Krupp
Distance rods	E. F. 60–0	Krupp
Axles	E. F. 60–0	Krupp
Gears	E. F. 60–0	Krupp
Cardan shaft	E. F. 60–0	Krupp
Jack shaft	E. F. 60–0	Krupp
Side frames	C. 46–0	Krupp

52 The ability of this metal to withstand shock was proved in this instance. The tables further illustrate the point.

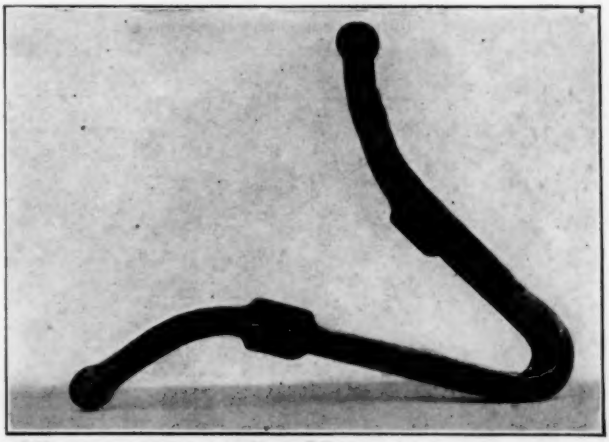


FIG. 7 FRONT AXLE
E F 60-0 Krupp Chrome Nickel Steel bent until ends touched and then released

SHOCK TESTS E. F. 60-0. KRUPP STEEL*

Blow no.	Deflection in inches	Data
1	0.71	Size test. Proof: 1.18 x 1.18 x 11.81 inches
2	1.30	Supports: 9.45 inches separated
3	1.89	Weight: 448 pounds
4	2.40	Fall: 39.37 inches
5	2.80	Specimen: doubled without rupture.

SHOCK TESTS OF C. 46–0. KRUPP STEEL*

Blow no.	Deflection in inches	Data
1	0.79	Size test. Proof: 1.18 x 1.18 x 11.81 inches
2	1.42	Supports: 9.45 inches separated
3	2.05	Weight: 448 pounds
4	2.52	Fall: 39.37 inches
5	2.91	Specimen doubled without rupture.

*Published by Krupp, and by the author in "The Automobile," Feb., 28, 1907.

53 The values cannot be compared with ordinary bessemer steel because that material would not withstand the abuse due to one single blow of the "tup." A good grade of carbon steel would act as follows:

SHOCK TEST OF GOOD CARBON STEEL

Blow no.	Deflection in inches	Data
1	1.34	Size test: proof; 1.18 x 1.18x 11.81 inches
2	2.28	Supports: 9.45 inches, separated
3	2.99	Weight: 448 pounds
4	3.46	Fall: 39.37 inches
5	3.82	Specimen: doubled without rupture.

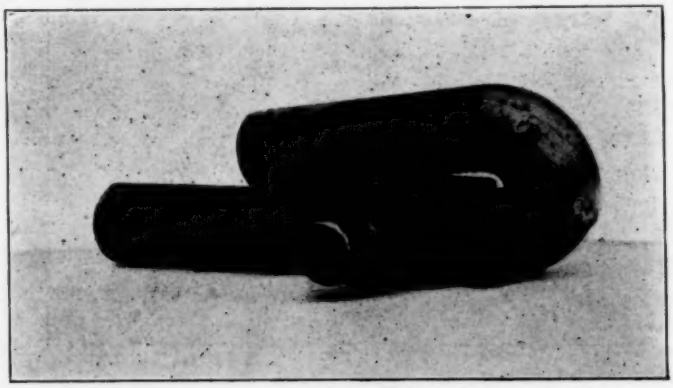


FIG. 8 E 120-0 KRUPP NICKEL STEEL DEEPLY NOTCHED AND BENT 180°

Normal physical properties:

Tensile strength	78,090	pounds square inch
Elastic limit	44,237	pounds square inch
Extension	25.8	per cent
Contraction	58.2	per cent

Diameter of test proof ½ inch, 40 carbon, A. O. H. steel, Krupp.

54 Carbon steel would seem desirable if it can sustain such severe shock loads, as this test indicates, and it can without question, if it is a low sulphur, low phosphorus, acid siemens product. This test has been duplicated many times, proof of which was furnished by "Brinell" in his "Impact Tests," as published by W. F. Harbord, "The Metallurgy of Steel," page 656, as follows:

No.	Blows	Footpounds	Remarks	Material
5	10	715	Not notched,	0.44 carbon
4	13	1184	Not notched,	0.34 carbon

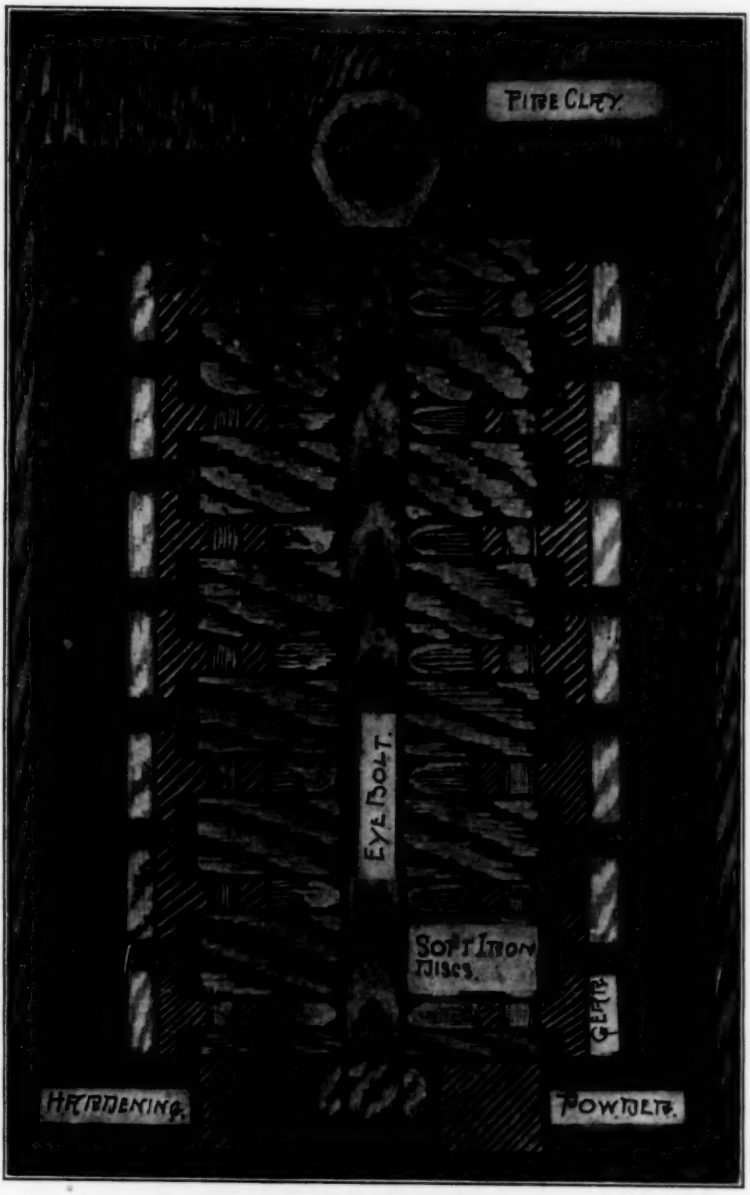


FIG. 9 NEST OF GEARS PACKED FOR CEMENTING

TABLE 1—SPECIAL AUTO STEEL

No	The Product from	Chemical Composition									Physical Properties						
		Cr	Ni	C	Si	S	P	Mn	Cu	As	Lbs per sq. in.		Per cent		Proof		Fracture
											T.S.	E L.	Ex.	Co.	diam. inches	length inches	
1	Midvale Steel Co	1.71	3.53	0.31	0.126	0.028	0.025	0.57			Impossible to make physical test						
2	" "	1.78	3.40	0.63	0.130	0.027	0.032	0.60			Impossible to make physical test						
3	" "	1.90	3.31	0.227	0.15	0.033	0.030	0.34			123,800	80,000	10.6	53.2	0.767	8	
4	" "	1.87	3.38	0.238	0.183	0.026	0.025	0.35			162,200	107,700	7.5	19.0	0.748	8	
5	" "	1.68	3.57	0.278	0.132	0.040	0.030	0.36			144,400	105,100	21.5	44.9	0.76	2	
6	Carpenter Steel Co.....	0.58	2.23	0.213	0.052	0.018	0.022	0.32			99,500	61,500	22.0	64.5	0.75	2	
7	Freid, Krupp, A. G.....	1.31	4.27	0.218	0.312	0.018	0.013	0.45	0.11	0.012	119,500	104,800	23.0	68.0	0.71	2	S
8	" " "	1.26	1.94	0.344	0.132	0.032	0.012	0.44	0.07	trace	96,500	77,100	26.0	67.5	0.74	2	S
9	" " "	1.40	3.31	0.31	0.26	0.028	0.015	0.41			109,100	81,400	23.0	61.8	0.75	2	S
10	Panhard & Levassor.....	0.63	2.19	0.38	0.112	0.046	0.025	0.16			Impossible to make physical test						
11	Panhard & Levassor.....			1.14	0.24	0.011	0.008	0.20			Impossible to make physical test						
12	S & M Simplex.....			0.98	0.25	0.012	0.009	0.19			143,000	71,100	4.8	2.6	0.762	8	
13	Broken crank shaft.....			0.108	0.09	0.09	0.108	0.79			51,200	23,400	17.6	34.8	0.75	8	
14	Panhard & Levassor	0.71	2.09	0.36	0.132	0.041	0.028	0.19			Impossible to make physical test						
15	Felix Bishoff	1.69	4.26	0.204	0.211	0.006	0.017	0.35			125,000	118,000	24.0		0.5	2	
16	Felix Bishoff.....	1.53	4.40	0.256	0.24	0.012	0.013	0.73			154,000	133,300	11.0	25.0	0.51	2	
17	Poldi-Austria.....	1.64	4.21	0.32	0.106	0.037	0.010	0.40	Wolf		105,000	65,000	23.0	63.5	0.505	2	
18	Crucible steel of Am.....	1.25	2.00	0.34	0.09	0.022	0.015	0.10	1.00		152,500	147,500	10.5	22.8	0.5	2	
19	Freid, Krupp, A. G.....										124,820	110,750	9.7	30.2	1.003 × 0.153	6	
20	E. W. Bliss Co.....		3.25	0.27	0.127	0.04	0.05				88,200	62,000	28.5	58.6			
21	Remington Rifle.....	1.07	3.40	0.29	0.19	0.018	0.015	0.34	vana 0.25		132,000	115,000	26.0	54.0	0.52	2	

Original investigations of steel either found, or used, in motor cars; excepting 22 and 21. Blank space indicates none present.

TABLE 2—SPECIAL AUTO STEEL

No.	Product	Chemical Composition										Physical Properties						
		Cr	Ni	Va	W	+	C	Si	S	P	Mn	Lbs. per sq. in. T.S.	Lbs. per sq. in. E. L.	Per cent Ex.	Per cent Co.	Proof diam. inches	Proof length inches	Fracture
22	Crucible steel of am.....	0.99	1.17		1.02		0.20	0.037	0.017	0.018	0.23							
23	Crucible steel of am.....	1.31	1.65		0.94		0.25	0.056	0.011	0.013	0.12							
24	Broken crank shaft.....						0.14	0.019	0.04	0.069	0.52	64,100	31,200	23.5	53.4	0.76	8	S¼C
25	Simplex Wheel hub.....						0.31	0.09	0.039	0.044	0.49							
26	Simplex side lever						0.27	0.107	0.028	0.01	0.53							
27	Broken cardan shaft ...						0.24	0.046	0 0 35	0.025	0.45							
28	Connecting rod.....						0.28	0.12	0 0 19	0.023	0.50	85,000	66,000	24.5	63.3	0.742	2	S
29	Carpenter steel.....	0.67	2.08				0.34	0.081	0.024	0.026	0.37	100,700	77,900	21.8	58.7	0.52	2	S¼C
30	Broken jack shaft.....		3.04				0.40	0.147	0.038	0.047	0.38	76,200	58,400	23.0	64.0	0.72	2	S¼C
31	Carpenter steel.....	0.68	2.09				0.41	0.09	0.023	0.028	0.36	172,500	131,000	2.4	0.41	0.516	2	
32	Crank shaft.....		3.44				0.29	0.14	0.046	0.052	0.37	91,500	64,500	22.0	59.5	0.531	2	S¼C
33	Exhaust valve.....		0.34				0.26	0.07	0.017	0.013	0.46	103,000	52,000	49.4	66.0	0.741	2	S
34	Simplex spring link.....						0.28		0.021	0.012	0.52							
35	Simplex steering arm....						0.23		0.036	0.020	0.62							
36	A bevel gear.....						0.26		0.041	0.020	0.53							
37	800 bad gears.....						0.22	0.26	0.038	0.024	0.68	79,500	47,600	19.0	43.0	0.74	8	C
38	Bohler Bros. (forged)....	0.50	3.00				0.40					100,700	73,825	8.7	29.7			
39	Bohler Bros. (forged ...	0.50	3.00				0.40					96,000	66,429	15.0	52.8			
40	Bohler Bros. (treated) ..	0.50	3.00				0.40					113,800	91,600	13.5	50.4			
41	Chassis frame extension .	1.64	4.48				0.24	0.198	0.008	0.012	0.18	171,500	155,800	23.0	61.8	0.491	2	S

55 Here is evidence on paper of what can be done, but actual attempts to duplicate these excellent results in practice end in defeat every time, for the following reasons:

a The steel is very often rendered crystalline in forging;
b The steel is sometimes burnt in forging;
c Notched bar tests disclose the inability of this product to sever in parts that, when designed, have shoulders, flanges, holes, or any irregularities of shape, that approximate a notch.

56 The notched bar tests by "Brinell" were given as follows and are offered as evidence of this fact.

No.	Blows	Footpounds	Remarks	Material
5	4	130	Notched	0.44 carbon steel
4	5	195	Notched	0.34 carbon steel

Measured up to the time of rupture.

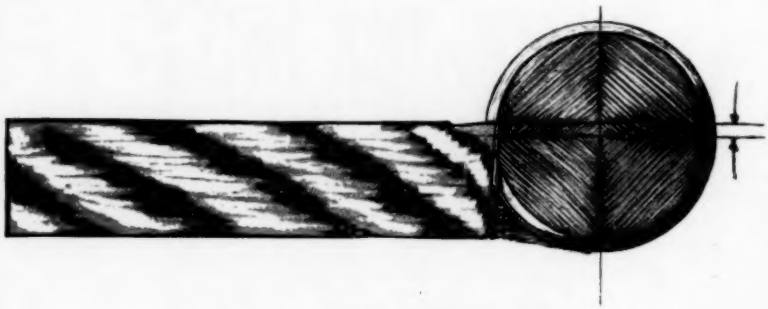


FIG. 10 TOOL SHAPE FOR HIGH SPEED

57 As will be observed, the impact in footpounds was very much less, and notwithstanding the rupture followed with 4 and 5 blows, respectively.

58 This phenomenon of carbon steel is probably too well understood by engineers in general to require more than the mention here given, but automobile engineers have learned by sad experience, that the impact "test" in the "laboratory" is as "varice loid" to "smallpox," as it were, if the automobile is substituted for the conventional impact test.

59 If then alloy steel is the product that will sustain shock loads, it is the steel to use for all parts that must absorb such shocks. The one remaining question is that of the "mixture" affording the greatest ease of working and the greatest factor of endurance.

MACHINING QUALITIES

60 Normal steel, no matter what its composition, will resist machining dependent more or less upon a coefficient of hardness that is not wholly represented by the tensile strength of the steel itself, but the relative values based on tensile strength would approximate the true situation if the hardness of the cutter could be made proportionate to the hardness of the material to be cut in a constant ratio.

61 For the purpose of this paper the coefficient of hardness can be set down as indicated by the tensile strength, assuming that the tools used will be strong enough to handle the hardest of steel to be considered. On the other hand, the value of the steel is not represented by the tensile strength, but it can be represented by a coefficient of usefulness deduced as follows:

$$f = (T.\ S. \times E.\ L.)\ \text{Ex.} = \text{coefficient of usefulness.}$$

62 This figure of merit takes into account not only the original strength of the steel, but its endurance and on this account it is a better method of comparison than the consideration of relative abstract values as the values in Table 3 will show.

63 Before going more deeply into the question of merit, it may not be amiss to repeat Professor Unwin's views about "Elongation" since merit is largely a matter of elongation. Professor Unwin points out, and no doubt the audience fully understands the factor elongation has two components:

a The elongation throughout the length of the test proof, that is, between enlargements;

b The local stretch and contraction of the section during the final stages.

64 While it is plain that the general elongation is independent of the diameter of the proof, it is equally plain that the local stretch varies with the sectional area of the proof, and it follows that no comparison between tests can be of any great value unless the diameter as well as the length of the proofs are the same.

65 The coefficient of hardness "*h*" (see Table 3) of steel must be taken into account for two reasons:

a The cost of machining increases with it,

b Bearing surfaces are dependent upon it.

66 When the coefficient of hardness is greater for carbon steel, that in itself constitutes a good reason for substituting alloy steel, but the figure of merit must also be taken into account. It is not

TABLE 3

APPROXIMATION OF RELATIVE MERITS

No.	PRODUCT	COEFFICIENTS		Process	Used for
		Hardness "h"	Usefulness "p"		
1	Chrome nickel steel			F	Change Gears
2	" " "			F	" "
3	" " "	19,226	2,160,280	F	" "
4	" " "	35,986	2,024,250	G	" "
5	" " "	11,614	3,384,250	E	" "
6	" " "	7,318	3,942,000	E	Testing
7	" " "	9,752	5,158,900	E	Crank shafts
8	" " "	6,674	4,513,600	D	Brake drums
9	" " "	8,260	4,371,500	E	Daimler parts
10	" " "			E	Change gears
11	High carbon steel			G	Motor valves
12	" " "	44,604	1,024,680	G	Motor valves
13	Mild carbon steel	4,238	1,312,960	B	Crank shaft
14	Chrome nickel steel				Change gears
15	" " "	10,125	5,832,000	E	Crank shafts
16	Chrome Nickel steel	25,845	3,127,300	+G	Crank shafts
17	" " "	7,319	3,910,000	E	Crank shafts
18	Chrome nickel wolfram steel	28,571	3,150,000	F+G	Testing
19	Chrome nickel steel	24,263	2,285,029	F+G	Side frames
20	Nickel steel	5,774	3,605,200	E	Crank shafts
21	Chrome nickel vanadium steel	9,500	6,422,000	F	Rifles
22	Chrome nickel wolfram steel				Springs
23	" " " "				Springs
24	Medium carbon steel	4,125	2,239,550	A	Crank shaft
25	" " "			C	Wheel hubs
26	" " "			C	Side levers
27	" " "			C	Cardan shaft
28	" " "	6,179	3,699,500	C+D	Connecting rod
29	Chrome nickel steel	8,192	3,893,480	E+F	Testing
30	Nickel steel	5,852	3,699,500	D	Jack shaft
31	Chrome nickel steel	126,458	728,400	G	Testing
32	Nickel steel	7,090	3,432,000	E	Crank shaft
33	High nickel steel	3,133	7,667,000	C	Motor valves
34	Medium carbon steel			C	Spring link
35	" " "			C	Steering arm
36	" " "			C	Bevel Drive
37	Medium carbon steel	6,689	2,414,900	C	Change gears
38	Chrome nickel steel	20,060	1,518,367	F+G	Ball bearings
39	" " "	10,832	2,437,380	F	Ball bearings
40	" " "	15,216	2,772,900	F+G	Ball bearings
41	" " "	14,274	7,550,900	F	Special forging
42					

easy to show this on paper, but by putting down the values of hardness it may be possible to advance a step and show by abstract methods, just when alloy steel should supersede carbon steel. But it would be a fallacy to assume that the tensile strength alone, or the elastic limit alone, or both combined, will govern this process, although it is admitted that the tensile strength does represent the hardness of steel in a general way.

67 It was by watching a tool that the author discovered that steel so hard that the tool bounced off *could be cut at a higher speed with the same tool*, and investigation along this line led to the belief, that increasing the elongation without a decrease in tensile strength brings further advantages. It is believed that this is the most important detail connected with the difficult work of fashioning alloy steel parts, and the coefficient of hardness is devised, taking into account that the metal is *heated* by the tool, thus rendering it *easier for the tool to do the work*.

68 If the metal is "short," *i. e.*, does not possess a good elongation, the tool clatters, and it cannot be made to take hold, so that the heating process then cannot be taken advantage of. It was a great surprise to the machinist who was unable to keep a "Novo" tool sharp at the speed he was operating, and when he was told to double the speed, found that the same tool on the same piece in the same lathe held its edge for several hours.

69 The coefficient of hardness then takes into account this condition to an approximate extent, of course, because absolute data on this subject are difficult to obtain. But if the metal is to be taken off cold, the coefficient of hardness must be really represented by the tensile strength, as at first suggested.

70 The true coefficient of hardness, taking into account high speed cutting—hot work—is found as follows:

$$C = \frac{T.S. + E.L}{Ex.} = \text{coefficient of hardness,}$$

in which:

$T.S.$ = tensile strength in pounds per square inch;
$E.L.$ = elastic limit in pounds per square inch;
$Ex.$ = elongation in per cent in 2 inches on ½ inch diameter test proof.

71 This equation is empirical, but timing tools and observing performances and the knowledge of the value of the steel in each case support the contention that its basic principle is worthy of esteem.

72 Now comes the more important point in relation to alloy steel, which spells success or failure in almost every instance.

73 To illustrate this point it will be necessary to call attention to the practice steel makers have, of "doctoring" their products to make them more attractive to purchasers. The doctoring process may be that of oil quenching and subsequent annealing, or it may be some other process. In any event the result is that in many cases the tensile strength and elastic limit are increased at the expense of the elongation.

74 True, the elongation may be held high enough to serve the purpose, but the cost of machining is by such a process enormously increased, while the factor of merit, or coefficient of usefulness of the steel is, as a rule, decreased.

75 It is possible to formulate a rule that will show the extent of damage. Such a process is as follows:

"For a given product, the coefficient of hardness—difficulty to machine—increases inversely as the square of the elongation."

76 To show this more clearly, a case in point will be taken. E.F. 60-0, Krupp steel bar having the following physical properties under a certain test gave the results tabulated below:

	Normal	Medium	Hard
T. S.	119,908	135,981	232,662
E. L.	100,596	114,361	222,285
Ex	16%	14%	6.8%
Co.	67%	62%	40.2%
	Coefficient of hardness		
2	= 13,781	17,881	75,824
Ex	= 256	196	46.5

and $$\sqrt{\frac{13{,}781 \times 256}{17{,}881}} = 16$$

while $$\sqrt{\frac{13{,}781 \times 256}{75{,}824}} = 6.8$$

77 This rule seems to hold for any treatment that can be given any one specimen of steel and it proves conclusively, if the rule obtains, that the steel mill should reverse its practice and charge more for high elongation, instead of charging for high elastic limit and the lowest acceptable elongation.

78 Of course, in the case of the E.F. 60-0 Krupp steel, or for any other product, the coefficient of hardness of the steel must be lower than the coefficient of hardness of the cutter by a considerable margin, else the edge of the cutter will be turned. The endeavor has been to

approximate these values and fix upon a relation, but the matter will require much further study, for as may be inferred, the problem is complex.

79 The most that can be said with certainty at the present moment is, that a coefficient of hardness of about 15,000 can be handled commercially, using "Novo," "Krupp," "Bischoff" or "Jessup" special grades of tool steel, costing from fifty cents to one dollar per pound. There may be other brands of tool steel suitable for the work, but those tried dulled on a far lower hardness than 15,000.

80 The best that can be suggested at this time by way of clearing up this point, is to fix a relation between the coefficient of hardness "h," as given in the Table 3 and a process index, also given in the same table.

81 We all know in a more or less exact way, just what machine tools will do and an attempt will therefore be made to refer to the matter in terms of the ability of machine tools. Of course, some machinists excel and can do much better, but the square roots of mean squares must be taken as true ability.

THE MACHINING PROCESS

82 In Table 3 one column is headed "Process" and a reference letter is placed in that column opposite each specimen of steel referred to. The reference letters are given meanings as follows:

A machines without difficulty in ordinary lathes or other tools using carbon steel cutters of the ordinary quality;

B machines only with difficulty with tools suitable for A;

C machines in ordinary machine tools using a middle quality of tool steel;

D machines with great difficulty under C conditions;

E machines with ordinary machine tools using the finest quality of tool steel cutters;

F can only be worked in large heavy machine tools using the finest quality of cutting steel;

G can only be ground; too hard to be cut by any known grade of tool steel, unless with the greatest difficulty.

83 Products that are so hard as to resist all but the grinder, can as a rule be annealed, and may then become softer, so as to take a new rating, but the dominant idea here is, to rate steel as it comes from the mill, since annealing takes time and has its own set of risks which become double when alloy steel is to be operated upon.

TABLE 4 SPECIAL AUTO STEEL

No	Products	Chemical Composition:										Physical Properties						
		Cr	Ni	Va	W	+	C	Si	S	P	Mn	Lbs. per sq. in.		Per cent		Proof		Fracture
												T. S.	E. L.	Ex.	Co.	diam. inches	length inches	
42	Special D. W. F.	1.50			1.00	cu.01												
42	A broken gear	3.26	3.26				0.50	0.11	0.03	0.04	0.16							
43	Projectile	2.60					0.98	0.27	0.019	0.014	0.27							
44	Armor plate	1.07	2.04		23.4		0.42	0.16	0.034	0.029	0.37							
45	Nature hard tool				6.12		2.07	0.08	0.014	0.010	2.14							
46	Magneto field						0.71	0.12	0.031	0.034	0.72							
47	Vanadium steel	1.120	3.34	0.31			0.21	0.07	0.019	0.014	0.42	164,800	121,600	15.0	31.8	½	2	
48	Vanadium steel			0.91			0.08	0.09	0.013	0.010	0.19	64,100	48,400	32.5	65.0	¾	8	S

84 As regards machine tools for handling alloy steel, there is much to be done, but the author finds by actual trial, that heavy tools are preferable in every way, as for illustration:

Old practice	New practice
20 inch lathe	30 inch lathe
16 inch lathe	20 inch lathe
12 inch lathe	16 inch lathe

85 The spindle speed of the new heavy lathe is higher than that which obtained for the old smaller lathe, and the cuts are taken heavy enough to bring the turnings off at a "dull red heat."

86 With chrome nickel steel, this result comes if a cut $\frac{3}{8}$ inch wide by $\frac{3}{16}$ inch thick is taken off at a speed of from 90 to 100 feet per minute. The coefficient of hardness of the steel in this case is:

$$\frac{110{,}000 + 90{,}000}{16} = 12{,}500$$

and the tool steel is "Novo," size of tools $\frac{3}{4}'' \times 2''$, air cooled from a temperature of 1400 degrees C, in a strong air blast from a blower. The tool looks as shown in Fig. 10, and as will be observed, it is backed off but slightly. The tool post must be rigid and strong.

87 The working of alloy steel will be briefly considered

a Die forging is the cheapest method possible, no matter what the cost of the dies;

b Lathe turning is the most likely to give the best results at the lowest cost per pound of metal removed;

c Special annealing facilities pay for themselves in even a few days;

d A Le Chatelier or equally good pyrometer and a good muffle furnace are indispensable;

e Hardening facilities should be complete and up to date;

f Compromising with tool steel is a waste of time;

g "Novo" steel drills are far superior to carbon steel drills for drilling alloy steel;

h Milling does not pay and should be eliminated in the design as far as possible;

i Shaper work should be cut out;

j Planers do not seem to serve very well in alloy steel work;

k A thousand dollars worth of redesigning will often save a hundred thousand dollars worth of work.

88 In concluding the question of the machining process it may be interesting to state that the author has developed a lathe—30″ swing

—with a 36″ x 42″ power feed platen, on which much of the work is set and is faced by means of fly cutters on the face plate of the lathe. The work can be fed into the cutter or crosswise, as the case may be.

89 The same type of lathe is fitted with "boring bars" for boring work, and work in centers or chucked work can also be handled. This type of tool then supersedes the boring machines, the miller, shaper, and planer.

90 The rigidity, accuracy, and nimbleness of a lathe is utilized while the cost of fixed tools as end mills, straddle mills, and the like, is eliminated, which is a very serious item in working alloy steel since carbon steel mills will not hold an edge, and "Novo" mills cost over much, and do not last indefinitely.

FORGINGS

91 One remaining question that can be discussed, is that of "forgings" aside from forgings in dies, and will receive but bare mention.

92 In the main, steel makers recommend that parts, if of alloy steel, be worked from normal stock, and that heating as in forging work, be avoided. As a general proposition chrome nickel steel forgings are just about twice the hardness of the same product in the normal state, and steel producers always must consider that users of steel in any attempt at annealing may fail to observe the requisites, although it is admitted that a properly conducted annealing process will restore steel to its original hardness which is, of course, a softer state than that which obtains if annealing is neglected.

93 Fig. 2 and 2*a* show the benefits to be derived by annealing, and the gains are twofold:

a The forgings machine more expeditiously;
b The parts are freed from internal strains and will serve their purpose more perfectly;

94 It is not uncommon to observe smiths who after forging parts raise the temperature to some high heat and then impede the cooling off process more or less. This is called annealing by them, but in most cases the product—chrome nickel steel—is rendered unmanageable by this process, and the microstructure of the steel so treated looks most unpromising. Forgings can be rendered soft by annealing just as expeditiously by the user as by the steel maker, but for the same results equal care must be exercised. The best way perhaps is to have the annealing process conducted as a separate operation after the forging work is completed and the forgings are cold.

95 If the forging work is not properly done, the annealing process will reflect its imperfections and since so much depends upon it, the annealing should be done by someone beside the person who does the forging. Annealing then serves as a check.

96 Friederich Krupp, and Essen-Ruhr, in a communication dated November 24, 1905, state their views on the subject, as follows:

> Steel E F 60–0 is a hard material and should therefore be treated with care during the heating. It is to be slowly and uniformly heated in a wood fire and after it has been heated in this way to such a degree that it cannot be touched anywhere, it is to be heated in the furnace to forging heat (1050 degrees Centigrade) but not before. The forging must not be continued for too long a time and is to be interrupted at *red heat*. If necessary, the steel is to be reheated.
>
> The cooling down of the material after forging must take place in the same slow and uniform manner as the heating and forging, for this purpose the forged pieces are to be placed in ashes and left therein, until they have cooled down.
>
> The annealing of the forgings is to be performed at a temperature of about 630 degrees Centigrade, the pieces, as a rule, being exposed for about two hours to this temperature. In the case of very thin pieces a shorter time of annealing will do. The heating and cooling down is to be done slowly, the same as in the case of the forging.

97 For the best results, a muffle furnace equipped with a pyrometer must be resorted to, because with alloy steel, definite temperatures must be observed.

98 There is one other point in relation to this question, *i.e.*, no matter how carefully the forging and subsequent annealing is done, the forgings will be overhard if the steel is inferior, not in comparison with carbon steel, *but as alloy steel*. It is not easy to understand why a slight difference in the carbides will make such a great difference in the hardness of annealed forgings, even when the process is very carefully conducted. In any case the fact remains and to show how marked the influence is, it may be pointed out, that product 9, Table 3, is rendered much harder by forging, than the product 15 of the same table. The main difference between these products is in the phosphorus and sulphur, although product 15 has a higher nickel content, and is lower in carbon. But the author has observed, that the annealing process is much more successful with steel of low sulphur and phosphorus, than it is, if these carbides are high, even in cases holding identical carbon, nickel and chrome.

99 As a matter of fact the product chrome nickel steel, if it is to be forged and it must be to build motor cars, will scarcely serve, excepting to greatly hamper the work, unless the chemical composition is held within narrow limits. The best product is that showing *the nearest approach to pure iron*, after subtracting chromium, nickel,

and carbon. These components, can be related to each other about as follows:

Chromium	Nickel	Carbon	Total
	Grade A		
1.60	4.50	0.23	6.33
	Grade B		
1.40	3.30	0.30	5.00
	Grade C		
0.70	2.00	0.35	3.05

100 If the iron in which these alloys are scattered is very pure, and of the same quality for all, each grade will be good, but grade A will respond to forging and heat treatment to the best advantage. If the respective grades are not to be the same as regards the purity of the iron, then the impurities will do the least damage in grade C and the greatest damage in grade A.

101 The impurities in the iron, for noteworthy results, should conform to the following:

Silicon	Sulphur	Phosphorus	Manganese	Total
		Grade A, under		
0.18	0.012	0.012	0.35	0.554
		Grade B, under		
0.20	0.018	0.015	0.40	0.633
		Grade C, under		
0.15	0.028	0.025	0.40	0.603

102 The values of the steel, can be set down as follows, if it is alloy steel to be forged:

a It is proportional to the square of the elongation for a given chemical composition.

b Phosphorus affects the values as follows:

For 0.01 phosphorus, value = 100
For 0.02 phosphorus, value = 50
For 0.04 phosphorus, value = 25
For 0.08 phosphorus, value = nominal.

c Sulphur if equal, to phosphorus, makes the estimate of value *b* hold as stated for phosphorus, but if sulphur is not held the same as phosphorus, then reducing sulphur below phosphorus does not increase the value of the steel. On the other hand, if sulphur ranges above phosphorus, the value of the steel will be depressed as follows:

Considering 0.01 phosphorus
For 0.01 sulphur, value = 100
For 0.02 sulphur, value = 75
For 0.04 sulphur, value = 37.5

Considering 0.02 phosphorus
For 0.02 sulphur, value = 50
For 0.04 sulphur, value = 30

Considering 0.04 phosphorus
For 0.04 sulphur, value = 25
For 0.08 sulphur, value = nominal

103 The remaining components, such as silicon and manganese, can scarcely be treated in the same way, and since there seems to be no relation that can be set down in relative terms, it may be best to avoid discussion with the understanding that the limits fixed in grades A, B, C will properly serve. It will be understood that this question of the relative values of alloy steel, from the sulphur-phosphorus point of view, is abstract and is beside the question of sulphur-phosphorus, etc., found in the various grades of steel. Moreover, the value rating given, can be given a money value, as well as value from the point of view of forging, subsequent annealing, and *difficulty in working.*

104 To show something of what can be done in forging grade A chrome nickel steel, forged specimens of very intricate shapes will be placed on view at Indianapolis, Ind., and it is possible that other forgings showing the ill effects of impurities in the alloy product will be available for inspection during the meeting. And finally in further relation to the question of heat treatment, it may be well to say a few words.

CEMENTING

105 Fig. 9 illustrates the method of packing gears in hardening powder and of excluding the air during the carbonizing process. That the packing process should be carefully performed, may generally be well understood, but it cannot be too completely taken into account.

106 The gears should be designed with a central flange for bolting, rather than to have flanges to one side, else warping will tend to be a conspicuous feature. Different sizes of gears should be "nested" in boxes by themselves. Moreover, the packing bolt should be of good size, and the "nest" of gears should be clamped as tightly as possible. The diameter of the "box" should be greater than the diameter of the gears by about three inches, and the hardening powder should be

rammed down tightly, after the nest of gears is placed centrally, exercising care to maintain the gears in this position.

107 The hardening powder can be ground bone, or the especially prepared Krupp product, used for this class of work. The clay seal at the top should be carefully placed, and the box will then be ready to go in the muffle furnace.

108 The time required in which to grow a satisfactory depth of "armor" depends upon the material of which the gears may be made, but a limit of four hours can be placed on the time if the products 5, 7, 9, 15, and 16 are used. The time must date from the moment the temperature throughout the "nest" is up to the desired cementing temperature.

109 The cementing temperature for these products lies between 880 degrees and 900 degrees C., and it should be closely held.

110 At the expiration of the desired time, the box can be removed from the furnace, the seal broken, and the nest of gears may be lifted by the eye of the bolt with a hook, and after quickly brushing the powder from the gears, they may be quenched in a bath of water. To lower the gears vertically by the eye of the bolt, and to work the nest of gears up and down in an ample bath of water, are well understood details.

111 After quenching, the gears will be ready for tempering. This process may be conducted by raising a bath of fish oil to a temperature of 250 degrees C. into which the nest of gears may be suspended and kept, at that temperature, for thirty minutes. Upon completion of this operation, the gears will be ready for service and if other parts are to be cemented, to subject them to the same careful treatment, is to insure success.

OIL QUENCHING

112 Gears are frequently oil hardened instead of being cemented, and such cars as the Panhard and Levassor in France, and the Simplex in America—given as illustration—are supplied with oil hardened gears, rather than with gears of the cemented variety. But all grades of nickel chrome steel will not serve the purpose, because some of the finest grades of this product fail to harden sufficiently as a result of this process.

113 The products that will oil harden are the following: 1, 2, 6, 8, 10, 14, 29, 31, and 40 and in general high carbon, medium nickel and low chromium with an excess of carbides as sulphur, phosphorus, silicon, and manganese, are represented in the products that will become file hard by oil quenching.

114 This process consists of raising slowly and uniformly the temperature of the gears to about 900 degrees C. and quenching in an ample bath of fish oil or cotton seed oil, after which the gears should be tempered at about 225 degrees C. in the same quality of oil.

115 Obviously finer steel cemented will render the best service, but it is justice to say that oil hardened gears of the other grades of chrome nickel steel serve far longer than any carbon steel product yet tried out.

116 To show that fine chrome nickel steel will not harden to file hard, a specimen so treated will be on exhibition.

117 In conclusion it may be said, the alloy steel question is an evidence of the fact that, taken as a whole, the modern automobile bears testimony to one of the greatest triumphs of metallurgy and mechanics, in alliance with all the means of exact science.

MATERIALS FOR THE CONTROL OF SUPERHEATED STEAM

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Non-Member

GENERAL

Since the introduction of superheated steam as a large factor in economy in stationary power plant use, the question of what type of material is best for the proper controlling of the resulting high temperatures has caused a great deal of investigation and interest.

2 In the following discussion of materials, some reasons will be given which are the results of experience and test, and other facts which we have accumulated from reliable sources will be shown. This article treats particularly of what might be called in a general way Piping Systems, which systems are made up of pipe, fittings, valves, and the necessary details connected therewith, such as joints, gaskets, etc., and are taken up separately.

PIPE

3 There can be little question as to the matter of pipe except quality. Of course, welded wrought iron or steel pipe is successful, but the difference in the quality of pipe under different conditions is very material. As in nearly all instances in a superheated steam station the old fashioned screwed joint is not satisfactory, it is necessary to do what is termed "work" the pipe—that is, weld, van stone, etc.—to make either a welded, van stone, or other joint of the same general description.

4 The accompanying cut is what is known as a "van stone joint."

5 For this work, the pipe made from open hearth steel is a great deal the best for manufacturing reasons, because it can be properly "worked," there being less carbon, and the quality is much more uniform. Bessemer steel pipe will very often act in a satisfactory man-

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ner, but one is never sure that Bessemer will run even and, therefore, troubles may result.

6 It is practically impossible to "work" wrought iron pipe. In making what is known as a "van stone joint," the pipe is nearly sure to split very badly, not only at the weld but all around its outer circumference.

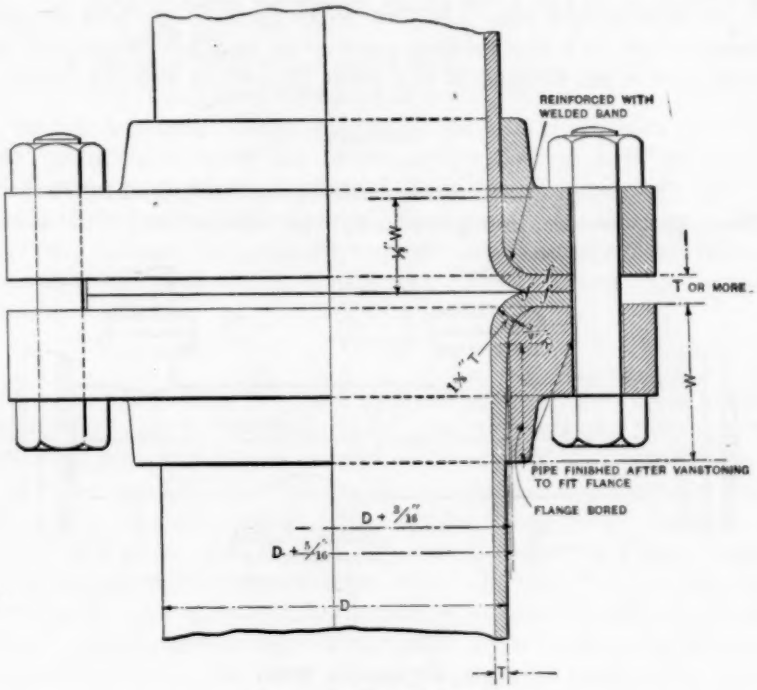

FIG. 1 VAN STONE JOINT

7 Nearly opposite qualities from those used for getting good results from "working" pipe are required for threading. A good quality of wrought iron will cut and thread more easily with standard pipe machines and standard dies than a steel pipe, and a Bessemer steel pipe will thread much more easily with standard dies than open hearth.

8 A great many manufacturers have difficulties in threading open hearth steel pipe, for the reason that they set the dies exactly the same as if they were cutting other qualities. This causes ripping of threads, etc. The die in a pipe machine should be set at a greater angle, with the radius of the pipe passing through the point of contact

of the die for soft steel, than it would be for other kinds, and this in itself will very often eliminate great troubles in this line. The question of lubrication, etc., is also important in this particular.

9 The ordinary commercial pipe will stand more pressure than the average person believes. A standard 1 inch piece of welded pipe will usually not break under 1600 pounds per square inch hydraulic pressure.

10 Full weight pipe, I believe to be perfectly suitable for any temperature and any working pressure up to 225 or 250 pounds, as long as it is not thinned at any point by cutting and threading.

FITTINGS

11 The design of fittings as generally manufactured for the different purposes are, in a general way, very satisfactory, with the one

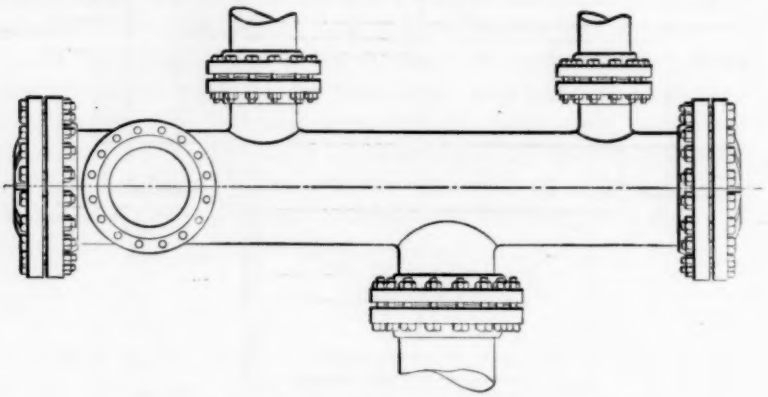

FIG. 2 WELDED WORK

exception that very few manufacturers on their standard articles include what is known as the "long fillet" between the body of the fitting and the flange. This is a very desirable point, due to the fact that at this place there is the greatest strain from shrinkage in the molds, which also tends to develop porous spots. Most large users of this type of material have learned this thoroughly and design their fittings specially; the chief difference in their design from that of the general manufacturer merely covering this point. The quality of the material in fittings, however, is a very important thing in connection with superheated steam.

12 The latest practice is to do away with fittings entirely on high pressure steam lines and put what are known as "nozzles" on the

piping itself. This is accomplished by welding wrought steel pipe on the side of another section, so as to accomplish the same result as a fitting. In this way rolled or cast steel flanges and a van stone or welded joint can be used. This method has three distinct advantages, to wit:

a The quality of the metal used, for reasons explained hereafter when the subject of the effect of heat on metals is taken up.

b The lightening of the entire work.

c The doing away with a great many joints.

13 As a general average, at least 50 per cent of the joints can be left out, and sometimes this proportion runs up as high as 60 or 70 per cent, according to the layout of the system.

14 If this method is employed, substantial welds must be made, not only to stand the pressures required but also the strains; this is accomplished successfully in Germany, England, and the United States.

VALVES

15 It is important to have a good design of valve. I believe that nearly any of the designs made by the good manufacturers are entirely suitable; such as a broken or solid wedge valve of the ordinary type, under the condition that all machine work is done thoroughly and the quality of metal used is satisfactory for the purpose intended.

16 It may be interesting to note here the effect of a large range of temperatures on a short piece of steel. By calculation, a piece of steel six inches long, heated 500 degrees, will expand 0.019 inch. This figure is put down to show how variations in the coefficient of expansion of metals by heat have a large effect on the permanency of a valve staying tight, and it can readily be seen that a small proportion of the distance given is sufficient to cause trouble.

METALS

17 I find that different authorities vary slightly in their statement as to what temperatures different metals will stand with good results. German authorities state that cast iron should not be used above 480 degrees F. Other authorities allow us to go as high as 575 degrees F. Above these temperatures in cast iron the limit of elasticity is reached with a pressure varying from 140 to 175 pounds. Under such conditions the material is strained and does not resume its former shape, and eventually shows surface cracks, which continue to grow until it lets go. These temperatures and pressures also lead in time to a

shrinkage of all parts, and to a structural alteration of the metal, which results in leakages in valves at the seatings. Therefore, it would seem that iron castings are unsuitable for both fittings and valves to be used in any superheated steam work. While they may last for some time, after a few years' use the metal becomes very weak and some cast iron has reached the point in weakness where if it were merely tapped lightly with a hammer it would break into pieces.

18 The only adaptable metal I believe to be cast steel. The results of tests by Bach on this metal for the effect of temperature are such that at 572 degrees F., the reduction in breaking strength only amounts to about 1.1 per cent and at 752 degrees F. to about 7.8 per cent. Therefore, it seems that this metal is practically capable of withstanding all pressures and temperatures up to at least 800 degrees F., without showing any appreciable weakness.

19 The influence of high temperatures on bronze, etc., is very material. At ordinary temperatures this metal has a breaking strength of about 34,100 pounds per square inch and an elongation of 36 per cent. At 572 degrees F. the breaking strength falls to about 19,500 pounds per square inch and the elongation to 11.5 per cent. At 662 degrees F., which is quite a common temperature, as it leaves the superheaters, the breaking strength of bronze only amounts to 12,200 pounds per square inch and the elongation at the breaking point is only approximately $1\frac{3}{4}$ per cent. This seems to eliminate entirely brass or bronze of ordinary composition for use with highly superheated steam.

20 The effect of temperature on nickel is very similar to that of cast steel and in consequence this material is very suitable for use in connection with highly superheated steam. Bach recommends that bronze alloys be done away with for use on steam lines above a temperature of about 390 degrees F. Even neglecting the special quality of nickel seatings, on account of the great toughness of this metal and the methods which can be used for securing rings of this substance to the valves and conical surfaces, it has the special advantage of having the coefficient of contraction and expansion with temperature almost exactly the same as that of cast steel, so that no slackness of the rings occurs and the valves remain absolutely steam tight. There are instances in which valves constructed with nickel seatings have been satisfactorily used with steam temperatures up as high as 932 degrees F.

21 Seats, discs, and bushings made of brass or plain bronze do not retain their shape.

22 For spindles on superheated steam work I strongly recommend nickel steel, which holds its shape and does not deteriorate with high temperatures.

23 Seatings in valves should not only be screwed in but also pinned in addition, using a fine thread which is very long, to give a tight joint. Seats should also have a flange on the top that makes a joint with the body when screwed down, which prevents the tendency to leak through.

JOINTS

24 I think it is generally acknowledged that the old fashioned screwed joint, no matter how well made, would not be suitable for superheated steam work. This leaves for discussion two general types, viz: welded joints, and what are generally known as van stone or climax joints; that is, any joint where the pipe is turned over the face of the flanges.

25 In welding a flange on a piece of pipe, great care must be taken to see that the weld is perfect because of the unequal thicknesses of the metals to be so welded. If the weld is thoroughly made, this type of joint is very good, although for erection purposes, due to the fact that the flanges cannot swivel, it does not equal the turned-over joint as mentioned above. The manufacturing expenses in making a welded joint are also much more for the same type of work accomplished, on account of the necessity of doing all finishing work after all rough work, such as welding and bending, has been completed. Therefore, the cost of welded joints is greater, not only for the work done but because of the increased expense in finishing on account of the necessity of employing methods different from those where the flanges, etc., were all finished before the joints were made, as is possible on the turned-over joint mentioned above.

26 In regard to the turned over or van stone joint, the quality of its manufacture seems to us the most important feature. This joint can be made in a careless way where the pipe is in no way thickened up and only faced on the front. A joint of this kind does not give good results, principally for two reasons:

a The thinness of the metal on the turned over portion; and

b On account of the recesses left between the back of the pipe on the turned over portion and the flange, due to the pipe not being finished at this point.

27 The writer believes, however, if this joint is properly made, it is equal to the welded joint as a manufactured article and superior to the welded joint as an article for erection.

28 To have this type well made, the pipe on the end should be thickened up in an amount sufficient so that after the joint is turned over there will be enough metal left to face the turned over portion on the front, on the outer edge, and on the back. We of course take for granted that the flanges are finished on the front. After the work above mentioned is done, the pipe should be as thick on the turned over portion as the original thickness, or very close to it. Increasing the thickness of the pipe on the end before going through the operation is done in several ways. In a general way, I consider any of the methods satisfactory. The point made of facing the turned over portion of the pipe on the back is an exceedingly important one, much more so than most people seem to realize. I have known instances where it has been found impossible to make a ground joint, for no other reason.

29 In reference to making up a joint, I believe that the face of all flanges or pipe where a joint should be made ought to be given a fine tool finish and have the face level, and then use a gasket of some description. A perfectly made ground joint is a good thing but it is very expensive, and it is hard to get the average contractor to furnish it in a perfectly workmanlike manner. Also, after it is so done, it is liable not to stay tight, on account of the tremendous expansion and contraction causing such strains that the joints are liable to open up, particularly when the pressure is taken off the plant. The simple expansion and contraction on the bolts that make up a joint would cause this.

GASKETS

30 There are large numbers of gaskets manufactured of all types and descriptions. It is very hard to take up this subject and be fair to each of the manufacturers, for the reason that practically no one can and has had experience with every type made to judge for himself, and hearsay would lead us to suppose that all of them are at one time perfect and at other times useless.

31 I have used a great many different types of gaskets, however, and have obtained the best results with a corrugated soft Swedish steel gasket with "Smooth-on" applied, and with the McKim gasket, which is of copper or bronze surrounding asbestos. The ordinary corrugated copper gasket is a very popular make and has been used a great deal. On superheated steam, usually sad results follow. There seems to be some peculiar action that causes this, as on superheated steam lines a corrugated copper gasket will in time pit out in some part of the flange nearly through the entire gasket. I have heard

a great many reasons given for the cause, such as electrical action, disintegration, etc.

32 The wear of a gasket depends largely on the method of pulling up bolts on flanges. In fact I believe that a great many troubles have occurred, because of imperfect erection. If joints are pulled up entirely on one side and left loose on the other, and then taken up on that side, trouble with the gasket is almost certain. The bolts should be taken up gradually all around the flange. The experience of the erecting crews on high class superheated steam lines is an exceedingly important thing. The average steam fitter is not suited to this type of work. He has had experience with lower pressures and less important tasks and after a piece of work is erected by him it is customary to find a great many leaks which are usually only eradicated after the whole joint has been broken and properly repaired. All these troubles can be eliminated by using only steam fitters experienced in the type of work under consideration.

BALL BEARINGS

A Discussion of Their Use in General and on Automobiles in Particular

By HENRY HESS, PHILADELPHIA, PA.
Member of the Society

The field of usefulness of the ball bearing is as wide as the domain of mechanical engineering, or at least that portion of it which is concerned with the support of rotating or oscillating parts.

2 The limitation imposed on the use of the ball bearing in no sense differs from that imposed on any other element of mechanism. It must be employed in accord with the general prohibition against overloading and in conformity with its individuality. That sounds axiomatic and is self evident enough; but self evident as it is, it is all too frequently disregarded.

3 Little information on ball and rolling bearings can be found in the usual engineering hand and text books. Generally the subject is dismissed with a casual reference; occasionally a formula for carrying capacity is given, but this is usually wrong.

4 Much matter is scattered through the technical press giving isolated experiences with a few bearings that happened to come within someone's observation. Insufficient information on almost every element that must be considered is undoubtedly responsible for the directly contradictory statements to be found and the generally accepted opinion that ball bearings are suitable only for relatively light loads.

5 This was the situation as Professor Stribeck found it, when asked to investigate the subject for the German Small Arms and Ammunition Factories of Berlin. This concern, having been induced to go into the manufacture of balls and ball bearings, very soon found itself confronted with the imperative need for a scientific basis, if the manufacture was to be removed from the domain of haphazard blind work-

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ing; resulting sometimes in success and sometimes in failure the one as much a result of pure chance as the other—a situation peculiarly galling to the German engineer with his reputation for examining everything in the light of every authority—whether that be the million candle search light of the modern, or the faint twinkle coming down the aisles of time from the rush light of the ancients.

6 With characteristic thoroughness Professor Stribeck took up the subject. He first applied the investigations of such men as Hertz, Auerbach and others, on the deformations of elastic bodies to the development of formulae for static conditions, then by exhaustive tests, determined constants for the materials and followed with an investigation into the conditions of relative motion, and finally concluded the whole by a long and patiently conducted series of observations with actual bearings, thus not only proving the previous theoretical investigation, but also developing data for the use of the work-a-day designer and engineer. That this labor has been crowned with success is evident enough from a consideration of the uses to which ball bearings constructed along the lines laid down have been put in the last ten years; these include not only light bearings for low and high speeds, but others for carrying the 24 ton armatures of electric flywheel generators at 500 revolutions per minute, etc. For various reproductions of working drawings of mechanisms mounted on ball bearings of rather unusual dimensions see a "Discussion on Bearings" by Henry Hess in the Transactions of the Society for 1906.

7 A word or two concerning the Central Laboratories for Scientific Technical Investigation (Centralstelle für Wissenschaftlich-Technische Untersuchungen), at Neubabelsberg near Berlin, may not be amiss. Several of Germany's chief engineering works rather more than a decade ago, having experienced the urgent need of the thorough investigation of the many problems continually arising in connection with their manufacturing operations, decided to endow a coöperative institution to which these could be assigned. Such work could there be done by people not burdened with other duties and laboring in an atmosphere as remote as possible from the pressure for immediate results necessarily existing whenever a laboratory is the direct adjunct of and is located within the purlieus of a manufacturing establishment.

8 The laboratories were erected at picturesque Neubabelsberg on the banks of the Havel within an hour's reach of Berlin and at an expense of some millions of marks. The annual maintenance is shared by the concerns in question. The writer happens to know that the share for one of these for one year amounted to about $150,000. It is this spirit of broadminded coöperation thus manifesting itself even

among competitive manufacturers that undoubtedly has much to do with the extraordinary way that Germany has, from rather a poor agricultural community, forced its way to third place among the industrial commonwealths, and all within the last thirty years.

9 This work of Professor Stribeck's undoubtedly is a classic in its field, so that no apology is needed for annexing a full translation and so making it available to the English speaking public.

10 The original German text has been followed almost word for word; while this will account for some turns of expression that are not strictly in accord with the rules of English grammar, the translator feels that to be better than even the slightest departure from the original. The task of translation was made particularly easy by the clear cut and definite style of the original.

CHAPTER I

The Translator's Résumé of Professor Stribeck's Report, and Notes Based on Experience

11 The translation of this report itself is referred to and should by all means be carefully studied, as it contains a very full, clear, and concise account of the theoretical and practical investigation and demonstrations on which ball bearing design must be based. For the statements and form of this résumé, the translator is alone responsible, but believes that it may be accepted as a correct condensation of Professor Stribeck's work.

12 Sliding bearings wear out by abrasion of the carrying surfaces. Ball bearings do not give out from wear and do not wear. They may be ground out by admitting grit, but that is as illegitimate a condition for ball bearings as it is for sliding bearings.

13 The only legitimate cause for the giving out of ball bearings is the stressing of their material beyond the limit of proportionality. Lightly loaded bearings can be so designed as to eliminate this cause and so insure practical indestructibility. For heavily loaded bearings this condition is not realizable within practicable dimensions, but the proportions may be so chosen that the over stressing does not result in breakdown within the lifetime of any mechanism to which the ball bearing is applied.

14 A knowledge of the elastic qualities of the materials at the hardness under which they are used is imperative. It being the elastic behavior that is important with ball bearings as with all other engineering structures, tests of balls, such as are commonly made to determine ultimate rupture when pressed into a steel plate and using the

depth of indentation of the plate or load at which rupture occurs as a measure of ball quality, are not only of no value, but are misleading.

15 The quality of balls and of ball races must be determined from their behavior under loads in the neighborhood of the elastic limit. Balls may be subjected to loads increasing as the shape of the supporting surface more nearly becomes complemental to that of the ball. A ball running between races having a flat or straight line cross section will not support as great a load as though the section were that of a curvilinear groove. Such groove naturally must never have a curvature equaling that of the ball, since that would substitute sliding for rolling contact.

16 The frictional resistance of a ball bearing is lower, the less the number of balls. Usually bearings can be designed to have between 10 and 20 balls. For that, with

P_b = total load on a bearing consisting of one row of balls;
P_0 = greatest load on one ball;
z = number of balls;

$$P_0 = \frac{5}{z} P_b \qquad \text{(Stribeck's Equation 11)}$$

The load carrying capacity of a ball is

$$P_0 = kd^2$$

in which

d = the ball diameter,
k = constant dependent upon the material and the shape of the ball supporting surface.

From Equation 11

$$P_b = P_0 \frac{z}{5}$$

substituting for P_0 from

$$P_0 = k d^2$$

gives

$$P_b = k d^2 \frac{z}{5}$$

17 As balls are usually made to English inches it is convenient to take the one-eighth of an inch as unity.

18 The following table gives *combination* values of k for different cross sections of ball race and for the materials used in the first ball bearings tried out and also for the improved steel alloys used later. These constants give P_b in kg.

19 If the cm. is preferred as the unit for the ball diameter, then the

tabular values for k are to be multiplied by 10, or more accurately 9.92.

*SHAPE OF RACES →			$R=\frac{1}{2}d$
k for older materials	3 to 5.0	3 to 5.0	10
k for improved materials	5 to 7.5	5 to 7.5	15

* The shape of the races will be shown at the meeting.

20 *Speed of rotation, in so far as it is uniform,* does not affect carrying capacity. (This applies to radial bearings, but not to thrust bearings of the collar type; in these the carrying capacity decreases with increase of speed.)

21 But speed is rarely uniform; variations cut down the carrying capacity; sharp variations of small amplitude, particularly at high speed, have the more marked effect. Their reducing action is similar to the battering effect of sharp load variations.

22 *Load variations reduce carrying capacity,* the effect increasing with the amount of the load change and the rapidity of such change.

23 *Accumulated experience* with various classes of mechanisms is so far the only available guide for estimating the reductions in the constants k that must be made to take these influences into account.

24 The carrying capacity of a complete bearing is no greater than that of the weakest cross section that comes under the load. This applies to all those forms which have curved race sections of maximum sustaining capacity, except at a point where an opening is cut to permit the introduction of the balls; such bearings are, as to load carrying capacity, governed by the weaker cross-section at that point.

25 *The calculated carrying capacity can be realized only if all balls sustain their share of the load.* It is obvious enough that if a ball is smaller than those on either side of it, it will not carry its share of the load; should it be larger it will carry more than its share and may be overloaded. Uniformity of ball diameter is essential. The permissible variation in ball diameter will be governed by the deformation produced by a relatively small part of the total bearing load, so that the balance of the load may be distributed over the several balls. Such permissible variations of ball diameters amounts to but little more than one ten-thousandth part of an inch.

26 *High finish of both ball and ball sustaining surfaces is essential.* The presence of grinding scratches will very materially cut down the cited values of the constant k. Of course this presupposes true surfaces underlying the high polish. It follows from this requirement that rust and acid must be carefully avoided as they are destructive of finish and truth of shape.

27 It may not be amiss to point out that *uniformity of quality*

of material, of hardness and of structure throughout are essential. The mischief of using balls having different values of k is not simply confined to the individual ball; if for instance one ball were materially harder and so deformed less than its mates, it would take more load and might therefore overload the material of the race, which would yet be entirely suitable under a division of the bearing load among a larger number of balls.

28 *The frictional resistances of ball bearings* have, by actual measurement, been found to vary from 0.0011 to 0.0095. These are the coefficients of friction referred to the shaft diameter, thus permitting direct comparison with those of sliding friction. The higher values are due to conditions that cause a preponderance of sliding as compared with rolling friction. It must be remembered that there is no such thing as a bearing having only rolling friction; that might be possible were balls and races made originally with absolute truth of surfaces and were such truth then maintained by the absence of deformation under load. Ball bearings having a coefficient of friction materially above 0.0015 under the greatest allowable load are inadmissible because too shortlived. The high resistance indicates the presence of too large an element of sliding.

29 A good ball bearing will have a coefficient of friction, independent of the speed within wide limits, and approximating 0.0015. This coefficient will rise to approximately 0.0030 under a reduction of the load to about one-tenth of the maximum.

30 The appended translation of Professor Stribeck's report is referred to for further details of his investigation.

CHAPTER II MATERIALS

31 The prohibition against overloading demands recognition of the characteristics of the bearing materials.

32 Any material may be used that will not, under the working load, be so deformed as to prevent pure rolling. That means an absolutely inelastic material and one which unfortunately is, and more than probably will remain, undiscovered. But a slight narrowing is admissible to make the demand read: *Any material may be used that will not, under the working load, deflect enough to prevent substantial rolling.* That recognizes that all materials deform under load. Such deformation means change of shape from the original truth and that in turn will cause some sliding combined with rolling; *this sliding must be held down to the irreducible minimum.*

33 Any material may be used that will not, under the working load, be stressed beyond its elastic limit; that is a limitation which is possible of attainment.

34 The tooth of time would be worn out against such a bearing. Its design is entirely practicable for light work, but for the heavier loads, the requirement would lead to, usually, impractical dimensions.

35 Fortunately, ball bearings, like various parts of the "Deacon's One Hoss Shay" are satisfactory if they last as long as their associated mechanisms. The requirement may therefore be modified to read: *Any material may be used that will not, under the working load, be stressed sufficiently beyond the proportional limit, to bring about its destruction before the lapse of a desired working life.*

36 These conditions permit the use of practically all of the materials known to mechanical engineering. With very few exceptions, however, the load conditions are such as to demand steels of the highest grades and these most carefully tempered. For automobile use, with which this paper is primarily concerned, no others can be considered. That puts out of the running all merely case hardened materials. In these there is always a more or less sharply defined change of structure at some distance below the surface. Continued working will cause a loosening of the hard shell from the softer core, soon followed by a breaking up and very characteristic flaking of the surface. See Fig. 1.[1] Usually this flaking is local; its action is increasingly progressive, soon involving the entire bearing.

37 What has been said of case hardened materials holds true also for those carbon steels in which the hardening is not carried substantially and equally through the entire mass.

38 I have here, Fig. 2, half of a ball. In this a sharp structural change due to hardening occurs at a fairly uniform depth of one-sixteenth inch below the surface. The ball has evidently been run under conditions which shifted the load over its entire surface; it was used in a running test and then broken to examine its structure. It so happened that the ball was caught just before it was ready to fail by flaking. The entire hardened surface has been loosened from the core in such way as to form an inner ball. Some relative movement of this shell and inner ball has undoubtedly taken place, as is evidenced by the polished condition of the inner surfaces. This specimen was presented me by Professor Stribeck, who retained the other half.

39 The ball is from a series of tests made to try out various materials; this particular grade is very evidently not suitable. It is interesting to compare its grain, Fig. 3, with that of Fig. 4 of the ball stock finally adopted.

[1]Fig. 1 to 4 inclusive will be shown at the Meeting. They were not prepared in time for publication.

40 What is true and required of the ball materials is even more so for the races. With time the ball presents its entire surface to the load, the small vibrations and changes of load being sufficient to frequently bring in a new axis of rotation. Not so the race; that is fixed and so always exposes the same surface element to the load attack.

41 *The requirements of a good ball are:*

a Truth of shape and size. The permissible limit of error will vary with the character of the material. In general, the better the latter, that is to say the smaller its deformation under a given load, the more accurate must the ball be. It is evident that, were a ball so much larger than its fellows as not to deform sufficiently under its share of the load to permit the others to carry, that it would then not only itself have to carry more than intended, but would also transmit more than intended to the supporting surfaces of the races. If, on the other hand, the ball were smaller than its mates, it would be underloaded or not loaded at all, and the others correspondingly overloaded. What has been said of variations in ball size, of course, applies similarly to variations from truth of outline.

All requirements will be met if the balls are true to shape within one ten-thousandth part of an inch and if all of the balls used in each individual bearing have a similarly small error in size. It must not be inferred that for materials of lower grade, larger inaccuracies are permissible. Were the load distribution the only factor, that conclusion might be justified; greater inaccuracy of size means greater deformation and therefore greater departure from sphericity and the substitution of too great a percentage of sliding for the rolling aimed at. Considerable initial variations from truth of shape have precisely similar results.

b Surface finish to a very high degree is also essential. What is usually considered a very good finish indeed may be characterized as totally inadequate. The recognition of grinding or polishing marks not only by the bare eye, but with an ordinary pocket reading lens condemns balls utterly; this is true of a bearing having long life under high loads and speeds. Oft repeated endurance runs under conditions where the finish was the only variable have abundantly proved this, at first unsuspected, fact. This was discovered while investigating an apparently inexplicable difference in lasting qualities. As life is too short for a try out under normal loads, overloads were resorted to; they demonstrated conclusively that the higher the finish, the better the endurance. The high finish must not be of the Brummagem or Reuleaux's "cheap but nasty" variety.

c The *elastic limit* should be as high as can be had. A limit of proportionality above the elastic limit is desirable.

d The *hardness and uniformity of hardness* throughout the mass of the ball to the highest attainable degree is essential.

e *Correct knowledge* and uniformity are more important than even these requirements of high elastic limit and hardness. It will not do to say that, though some balls of a lot may do better than others, the design may be based on the poorer ones. That would result in the better balls carrying more than their share of the load, much as and with the same bad effects described while considering truth of shape and size. Lower quality, provided it is uniform, can be allowed for. It will then merely affect dimensions.

42 *Ball making machinery* has arrived at a very considerable state of perfection; but balls within a limit of one ten-thousandth of an intended size are not yet being made without the sacrifice of other qualities. That is, however, not important beyond having some slight bearing on cost, since it is perfectly feasible to select and grade balls within the desired limit; but the hardware dealer's word for uniformity of size is not a safe guide; he is perfectly honest in throwing odd lots of $\frac{5}{8}$ inch balls into one box and in thinking the customer who objects because they vary a half-thousandth, or even two, a "finicky crank."[1]

CHAPTER IV

VARIOUS TYPE CHARACTERISTICS

In the automobile, as in all other mechanisms, the journals deal with loads having various directions. In the order of their occurrence and importance they are:

Radial loads—acting at right angles to the shaft axis;
Thrust loads—acting parallel to the shaft axis;
Angular Loads—these may always be resolved into, or considered as made up of radial and thrust components.

RADIAL BEARINGS

2 Other things being equal, it is always best to arrange sustaining surfaces at right angles to the load direction. That gives the design of Fig. 5. Better carrying capacity is had from the modification in Fig. 6 in which races of curved cross-section are substituted for the straight line ones of Fig. 5. These grooved races have the advantage of greater

[1] Chapter III will be read at the Meeting, but at the time of going to press was not ready for publication.

sustaining capacity, as referred to more in detail elsewhere; as the tangent to the curve is normal to the direction of the radial load, the bearing is of the radial type.

3 As is shown elsewhere, the sustaining capacity of the bearing is dependent on the degree of curvature of the race cross-section, being greater as the latter more nearly approaches equality with the ball curvature.

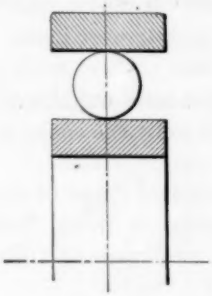

FIG. 5

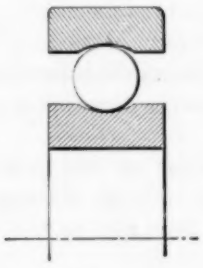

FIG. 6

4 Cutting a local groove from the side into a race for the purpose of assembling the balls between the two races is general (see Fig. 7), but is not good practice. If such cut is confined to one race which is then so held in the mounting as always to keep the opening at the unloaded side of the journal, this is at least defensible practice. The carrying capacity is then not decreased as the load is carried by cross sections of maximum sustaining ability. Unfortunately, this demands the use of two differing designs; the one with the cut in the outer race,

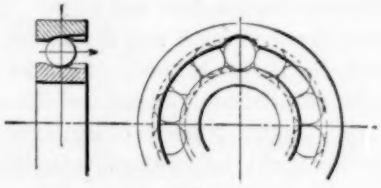

FIG 7

the other with that placed in the inner race, according as the shaft or the housing rotates; the first case is the usual one of an ordinary journal; the second is found in wheel-hubs, etc. That occasional arrangement in which both hub and shaft rotate cannot be taken care of by this design.

5 It may be said here that high loads are dealt with. So long as the loads are low enough to be within the sustaining capacity of the

straight line cross section, such local straight section at the filling opening is of no moment. At high speeds this does not hold true, since then the catching of the balls at the junction of the filling, opening with the race, results in damage to the balls and, through these, to the race surfaces

With the cut in both races the carrying capacity is reduced to that of the straight line section at the side of the cut, since one or the other cut must come under the load in each revolution.

THRUST BEARINGS

6 The requirement that the sustaining surfaces should be at right angles to the direction of the load is responded to by the collar type of Fig. 8.

7 What has just been said of the cross sectional shape of the race surfaces in their relation to carrying capacity in radial bearings applies here also to the thrusts. Since the two races and the ball

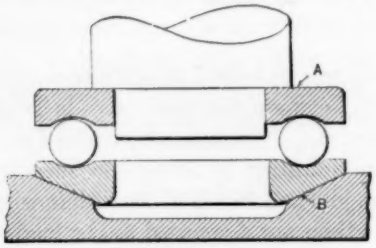

FIG. 8

series do not form a unit handling as one piece, the need of a filling opening for the balls from the side does not arise. These bearings are frequently made with the surfaces A and B parallel. Provided such parallelism is secured, the design is good. Practically it is not realizable, since also similar parallelism between the collar of the shaft and the seat of the housing, though possible of initial attainment, cannot be maintained under the slight deflections due to the load. It must be borne in mind that initial errors in workmanship or deflections of a thousandth of an inch will cause the balls at one side to carry the entire load. For a given case this demands a bearing of needless size. By seating the one plate on a spherical surface, as B, this plate adjusts itself in such wise as to distribute the load over the entire number of balls.

8 Speed very decidedly enters into the carrying capacity of this type of bearing as a factor; so much so in fact as to greatly reduce its utility for speeds above 1500 revolutions per minute.

ANGULAR LOAD BEARINGS

9 Of these there are shapes and modifications innumerable. Fig. 9, 10, 11, and 12 may be taken as typical and representing two, three and four point contacts. In order to secure rolling, the contact points of balls and races should form points of a cone of rotation, whose apex lies in the center line of the shaft, or they may form points on the surface of an imaginary cylindrical roller that is parallel to the shaft. The defect in all of these forms is their adjustable feature. This places them absolutely at the mercy of every one capable of wielding a wrench; a bearing that has been properly proportioned with reference to a certain load, will be enormously overloaded by a little extra

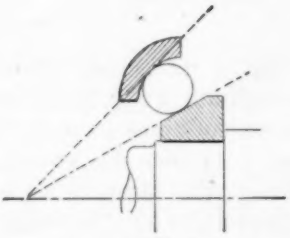

FIG. 9

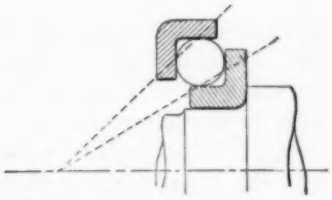

FIG. 10

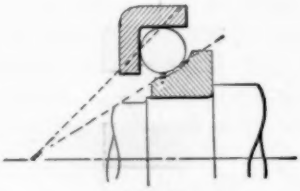

FIG. 11

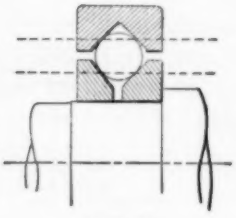

FIG. 12

effort applied to the wrench. Or the bearing may be adjusted with too much slack with consequent rattle and early demise. The prevalent idea that these bearings may be adjusted to compensate for wear is erroneous. Wear will form a groove on the loaded side of the race, deepest at the point of maximum load, about as in Fig. 13.

10 It is obvious that adjusting the cone endwise will only cause the balls to be more tightly pinched between the sound portions of the races, probably with sufficient pressure to overload; that will then cause an early flaking out, as shown at *A* in Fig. 14. These rough surfaces will quickly attack the balls and, progressively, the entire race.

The annular non-adjustable type of bearing will always, other things being equal, perforce have the important advantage of immunity from overload by maladjustment, no means for adjustment being provided.

11 Theoretically it would seem that the radial bearing would be incapable of carrying thrust load, owing to the wedging of the ball between the races. Fig. 15 shows the condition with the ball abso-

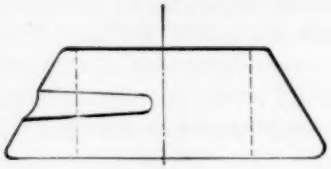

FIG. 13

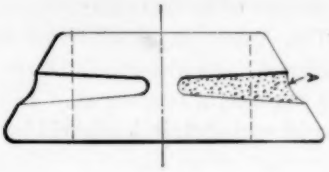

FIG. 14

lutely filling the space between the races. Fig. 16 shows the ball not quite filling this space. Fig. 17 shows the condition of Fig. 16 under the influence of a thrust load. The ball does not come in contact with the race grooves where these are deepest, but on one side, so that the tangent to the race curvature at the contact point forms an angle with the line of thrust. For Fig. 15 this angle would be infinitely small and the wedging action considerable. A calculation of the amount of the wedging action for Fig. 16 and 17 with the radial freedom

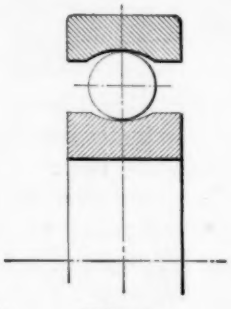

FIG. 15

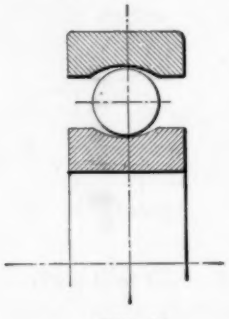

FIG. 16

permissible in the bearings still indicates an inadvisably large amount of wedging. But actual running tests as well as a large fund of accumulated experience have absolutely proven that these bearings will carry much more thrust load than the calculation of the theoretical wedge angle indicates as possible. It is probable that the deformation which we know occurs at the point of ball contact and that results in small actual surface areas of contact instead of mere points,

has a mean tangent to such compression surface of greater inclination, and that the wedge is therefore more blunt.

12 It has been experimentally determined that the thrust carrying capacity of the uninterrupted type of an annular bearing is to the radial capacity as $\frac{1}{10}$ to $\frac{1}{4}$ to 1, depending upon the relation of ball

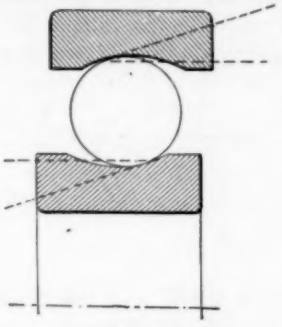

FIG. 17

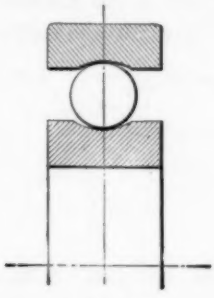

FIG. 18

diameter, race curvature, and number of balls. It has also been experimentally found and confirmed by experience that speed has very slight influence on this thrust carrying capacity; for speeds above 1500 revolutions per minute these radial bearings of the uninterrupted race type are more efficient thrust carriers than the collar type.

13 This is characteristic, however, only of the uninterrupted radial type. Those forms in which the balls are filled in through an opening in the side, Fig. 18, may manifestly not be subject to end thrust, as that would cause the forcing of the balls into the interruption and their destructive pinching.

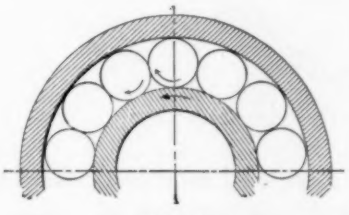

FIG. 19

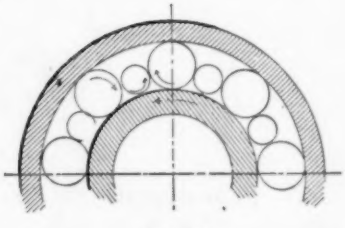

FIG. 20

14 It is held by many designers of ball and roller bearings and others as well—that in such bearings adjacent balls or rollers are pressed against one another with considerable force. With the inner race of Fig. 19 rotating as indicated, the balls or rollers will also roll as indicated. The surfaces of the balls or rollers roll in opposite direc-

tions and therefore with sliding friction. This is assumed to be a serious defect by those who reason that these surfaces contact under pressure. The same general cure in forms innumerable has served to glut the records of our and various other patent offices. This cure, see Fig. 20, consists in the provision of smaller balls or rollers interposed between the larger ones, so that all contacting surfaces roll relatively to one another. The remedy is, however, fallacious in that it brings about the very condition it seeks to avoid. If two large balls,

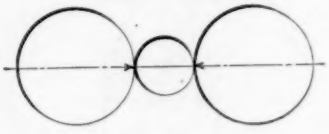

FIG. 21

FIG. 22

Fig. 21, compress a smaller one between them, and the three have their centers connected by a straight line, they will retain their relative positions. If, however, the interposed roller or ball, Fig. 22, has its center to one side, then this roller or ball will be forced outward. The resort to a cage for retaining the interposed roller or ball, results in the latter being pressed against the sides of the cage and in the forcible sliding contact that it was intended to avoid.

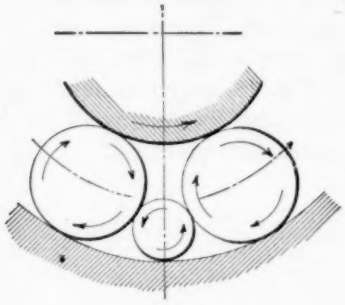

FIG. 23

15 In another design, Fig. 23, the interposed member is brought into contact with the race. Following out the directions of rotation shows that the various rollers or balls are in rolling contact, but that the interposed member has the wrong direction with reference to the race against which it is forced.

16 These designs are all based on a failure to recognize an axiom in mechanics, according to which a force whose direction is normal to the supporting surface has no component in any other direction.

If a loaded plank, Fig. 24, is carried on two rollers, and plank and ground are parallel, the rollers will neither approach to nor recede from one another. If the plank is not parallel to the ground, but bent down between the rollers, Fig. 25, the rollers will be forced apart. If the plank were oppositely curved upward, the rollers would be forced toward one another.

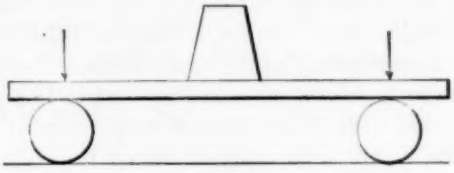

FIG. 24

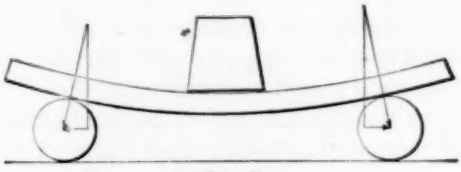

FIG. 25

17 As parallelism is concentricity with an infinite radius of curvature, the parallel plank and ground may be regarded as elements of a roller bearing of infinite diameter. A mere change in diameter, while retaining the concentricity of the two races, does not alter the conditions, from which it follows that the load carried by a ball or roller does not press the balls or rollers against one another.

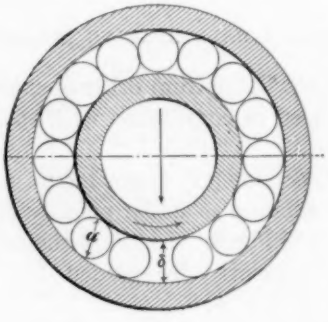

FIG. 26

18 This may be considered in another way. With the shaft of Fig. 26 loading the inner race the latter is (fallaciously) assumed to

act as a wedge, forcing the balls at the bottom apart and consequently producing pressure between the balls at the top. In that case the space δ must be rather smaller than a ball diameter d. The rotation of the inner race carries the balls around the bearing; the diameter d is therefore forced through the smaller space δ. To do this the ball must lift the inner race. The force to do this is imparted by the load, and is equal to the rolling friction and can therefore amount to but a fraction of that load. We would then have the absurd condition of this smaller force overcoming the larger original force. Were we to assume that the inner race is not raised by the ball in passing, but that the ball compresses sufficiently to get through, it would mean that the absurdity of the small force represented by the rolling friction was sufficient so to deform the ball or roller.

19 If a vertically loaded bearing which is not quite filled, as Fig. 27, be rotated slowly enough for observation it will be found that the balls are separated near the top and slightly forward of the vertical in the direction of rotation, and that the balls, under the influence of their weight, drop through this gap with a slight click; this click is familiar enough to those who have not yet entirely forgotten the days when their noses cultivated the intimate acquaintance of their bicycle handlebars. It is this click which is responsible for the high note of the high speed ballbearing of that type in which the races are filled with balls.

20 I may seem to have dwelt unnecessarily long on this fallacy of ball and roller bearing design; its surprising prevalence must be my excuse.

CHAPTER V

CORRECT BALL BEARING MOUNTING

Ball bearings do not differ from other elements of mechanism, in that they must be used in conformity with their individual characteristics.

2 Some of the directions for correct mounting that are here cited must be absolutely adhered to under penalty of failure. These are given in a, b, c, d and e of Par. 3. To follow the others will be safe engineering; they are frequently disregarded, but such disregard is a standing invitation to trouble.

3 A strict adherence to all of the directions—and they are neither many nor troublesome—will result in a reliability as near to absolute as even the most exacting can expect—a reliability far beyond that of any other form of journal—and such reliability is gained with the

advantages of a practical absence of friction, small space occupied and the minimum of attendance. Surely these are advantages enough to make a careful study and following of the directions worth while.

a The proper size selection for the load must be made. Rated capacities are usually for steady loads and speeds. Variations from these conditions demand recognition by a suitable cutting down of the listed capacity.

b Bearings must be lubricated. The oft repeated statement that ball bearings can be run without lubricant is pernicious.

c Bearings must be kept free of grit, moisture and acid. This prohibits the use of lubricants that contain or develop free acids. It is entirely practicable, by very simple means, to respond to *b* and *c*.

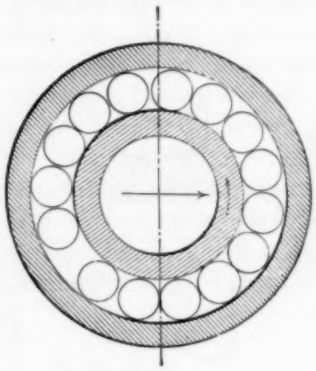

FIG. 27

d The inner race must be firmly secured to the shaft. It is best to do so by a light drive fit, re-enforced by binding between a substantial shoulder and a nut.

e The outer race must be a slip fit in its seat.

f Thrust ought always to de taken up, whether in one or opposite directions, by the same bearing. That avoids all strains due to flexure of the shaft or of the housing or due to temperature variation and, while doing away with the considerable shop costs inseparable from correct lengthwise dimensioning, avoids the danger of excessive end loads from forcible assembly consequent on an inaccurate lengthwise location of parts.

g Bearings should never be dismembered, or at least never more than one at a time; that will avoid the danger of mixing balls from different bearings; such balls from different bearings are apt to vary more than is permissible for the individual bearing.

ILLUSTRATIONS OF CORRECT MOUNTINGS

4 The ball bearing in its application to heavy work and serious engineering is of so recent a development that really very little information as to correct mounting arrangements for the various conditions that arise in practice is generally available. My experience has been that faulty mountings are so general that it is desirable to give elementary illustrations rather more in detail than would be considered necessary for a more familiar mechanical element.

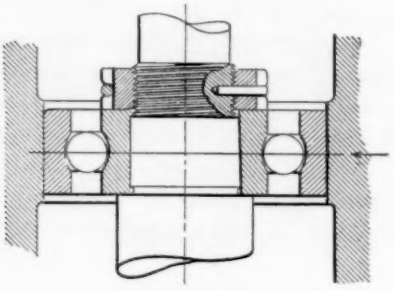

FIG. 28

RADIALLY LOADED ENDWISE FLOATING SHAFT

5 The inner race is a light driving fit on the shaft and is securely clamped between a shoulder on the shaft and a nut. As the edges of the bearing races are rounded, the shaft shoulder should be high enough to get a firm grip on the side surfaces; about half as high as the race thickness—rather less for larger bearings, rather more for small bearings—is good practice.

6 The outer race is a sucking fit in the housing so that the bearing as a whole can respond to relative shifting of the shaft and housing without being subjected to an uncontemplated end thrust through the balls.

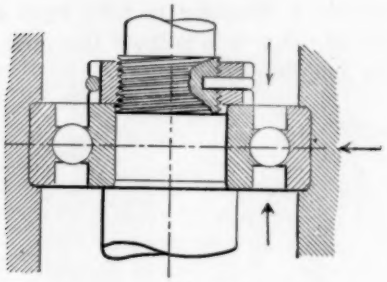

FIG. 29

RADIALLY LOADED SHAFT HELD AGAINST ENDWISE MOTION IN EITHER DIRECTION

7 Also for thrust load in either direction. Never more than one bearing should thus be held endwise as to its outer race. This differs from the preceding mounting only in having the outer race also secured between shoulders. Frequently, as in electric motors, some float of the shaft is wanted; a corresponding clearance between these outer shoulders and the race is then provided. This arrangement and the preceding one are usually found combined on the same shaft, which is then held endwise at one point only, so that temperature changes, or deflections of shaft or of bearing can cause no cramping. This mounting will take end-thrust also and in opposite directions. It is very frequently useful where it is desirable to take both thrust and radial load on one bearing.

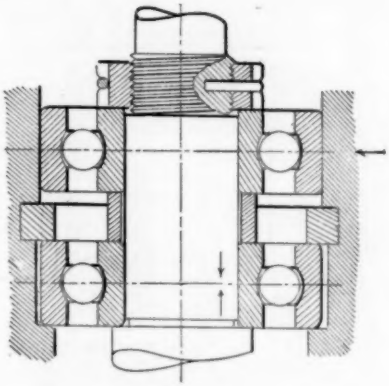

FIG. 30

SEPARATE RADIAL BEARINGS FOR RADIAL AND THRUST LOADS

8 It is occasionally desirable to take thrust load on bearings of the radial type, while the space available does not permit of a single

radial bearing of sufficient diameter to take both loads. A second may then be so mounted that it is entirely free circumferentially and so cannot be loaded radially.

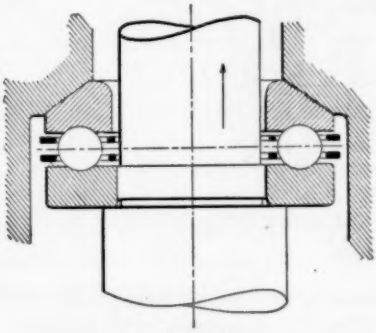

FIG. 31

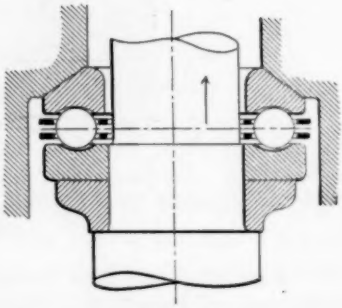

FIG. 32

THRUST LOAD IN ONE DIRECTION ON COLLAR BEARING

9 The stationary race is provided with a spherical seat so that it will distribute the load over the complete ball circle.

10 In order to permit compensating shifting, the fixed plate must be radially free of the shaft and of the housing. The shaft shoulder should reach high enough not to subject the rotating race to bending strains tending to dish it. Where it is inconvenient to provide a sufficient shoulder on the shaft, it is advisable to insert a suitable washer, as shown in the modification, Fig. 32.

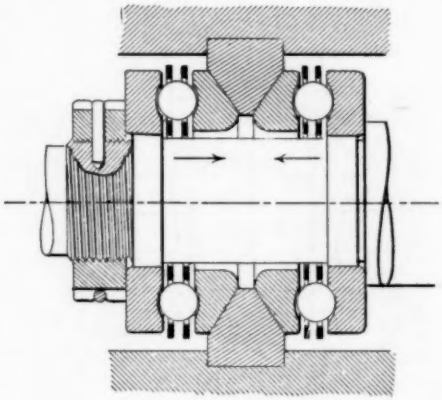

FIG. 33

THRUST LOAD IN TWO DIRECTIONS ON TWO COLLAR BEARINGS

11 This is simply a doubling of the preceding unit to provide for the reverse thrust.

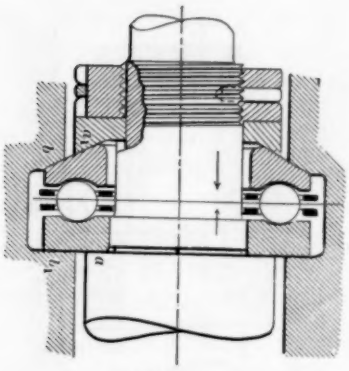

FIG. 34

THRUST LOAD IN TWO DIRECTIONS ON ONLY ONE COLLAR BEARING

12 This arrangement economizes in room, in cost of bearings and in number of parts.

13 While the shaft shoulder a and the housing abutment b are in intimate contact with the races due to the transmission of the thrust loads, the other abutment b' and the shaft nut a' are not under pressure and are slightly relieved by the spring of the parts, so that the lubricant can get between the surfaces. Reversal of the thrust will bring the erstwhile free shoulders into contact under load and clear the others.

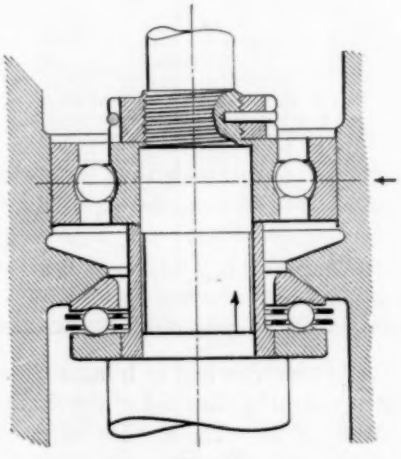

FIG. 35

RADIAL AND ONE DIRECTION THRUST ON COLLAR BEARING

14 This combination is an obvious one, not differing in principle of the mount from those already shown.

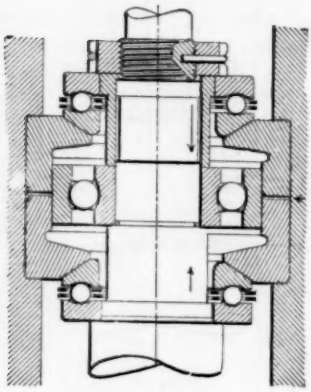

FIG. 36

RADIAL AND TWO DIRECTION THRUST ON TWO COLLAR BEARINGS; USED IN MOTOR BOAT AND YACHT PROPELLER SHAFTS

15 This is an obvious extension of the preceding arrangement in accord with the intended function. Attention may be drawn to the distance piece for transferring a binding thrust to the inner race of the radial bearing.

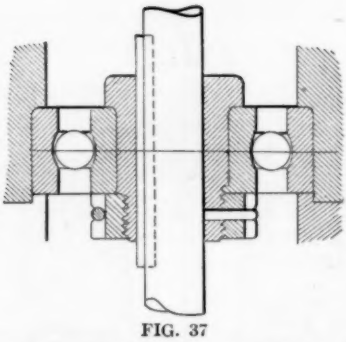

FIG. 37

SHAFT FLOATING THROUGH INNER RACE

16 It is occasionally inconvenient so to arrange an assemblage of parts that the inner races can be clamped to the shaft, or it is desirable to have a shaft slide through it. The peening effect of vibratory loads concentrated on so narrow a zone of the shaft as the race width would cause the cutting down of the shaft. Introducing a sleeve, on which the inner race of the bearing is firmly clamped endwise, gives a sufficiently long surface between sleeve and shaft.

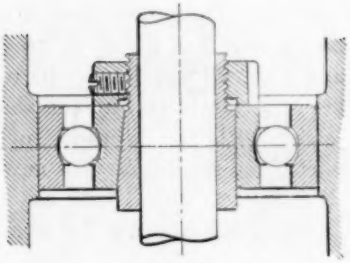

FIG. 38

ADAPTER BEARING FOR CONTINUOUS OR DRAWN SHAFTING

17 The bearing is tapered as to bore. Driving the split bush in will clamp both bearing and shaft and compensate for such size variations as are usually found in shafting. The nut must not be used to draw the bush in, but merely as a lock to hold it after it is driven home with a soft hammer.

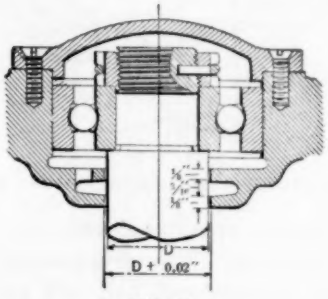

FIG. 39

BEARING CLOSURE—SINGLE GROOVE—NO PACKING

18 It is necessary so to enclose a ball bearing that the lubricant will not be lost by leakage and that foreign matter will be excluded. This shows one way that has been found efficient. Where a shaft terminates in a bearing, the outer end is best closed in completely by a suitable cover. Where the shaft passes out, a flange should be brought down to the shaft and bored out not over 0.02 inch in diameter larger than the shaft; this flange should be separated into two lips by an annular groove which may be either cored or bored, as may be convenient. The lips should not be less than $\frac{1}{8}$ inch wide and should have sharp edges; rounding them over will defeat their object.

19 The groove should be provided with a hole or narrow slot at its lowest point to communicate with the bearing oil space. For a rotating frame—as a vehicle hub—several such drains should be distri-

buted around the groove. The groove should have a width of not less than $\frac{3}{16}$ inch and a depth of about $\frac{5}{16}$ to $\frac{3}{8}$ inch. Filling the groove with a packing material will destroy its object just as soon as the packing has worn sufficiently to hug the shaft no longer. This arrangement does away with the necessity of all spraying rings, grooves, collars, pockets, and similar devices now much used on electrical machinery. It fails of its object with any type of bearing subject to radial wear, as that will increase the small clearance between the shaft and lips.

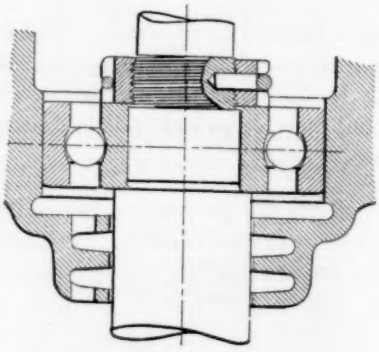

FIG. 40

BEARING CLOSURE—DOUBLE GROOVE—NO PACKING

20 This differs from the previous closure only in the provision of a second groove and third lip. The arrangement is employed where water is occasionally encountered and will prevent its entrance. What little may find its way past the outer lip into the outer groove is soon drained out of that again through the holes provided.

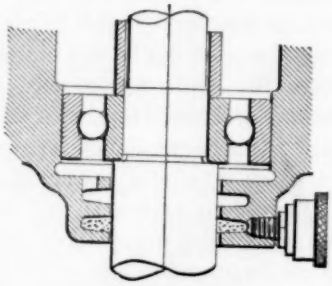

FIG. 41

BEARING CLOSURE—DOUBLE GROOVE—GREASE PACKING

21 Where much impalpable grit is present, as in emery and other grinding machinery, a packing that actually hugs the shaft is necessary. Filling the outer groove with a fairly consistent grease will provide such a packing without introducing friction. A grease cup of the spring loaded piston type will automatically maintain the integrity of this packing. Its use entails some attention to the proper balance of grease consistency and spring pressure under the extremes of temperature likely to be encountered. A manually adjusted grease cup is less delicate, but must occasionally be given a turn.

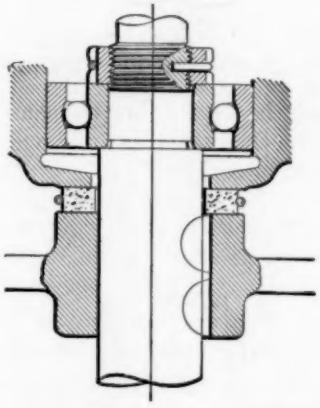

FIG. 42

BEARING CLOSURE—TAKE UP FELT RING

22 Some prefer a felt ring packing. They will find that to soak such ring in good soft paraffin and then to pass a split spring wire ring around it will force the outer edges of the washer outward to more intimate contact and cause the bore to hug the shaft, even as the ring wears. The action will be improved if the ring is not stamped out as a washer, but laid up from a strip with the ends scarfed; that will permit it to close up more freely under the constraint of the encircling spring.

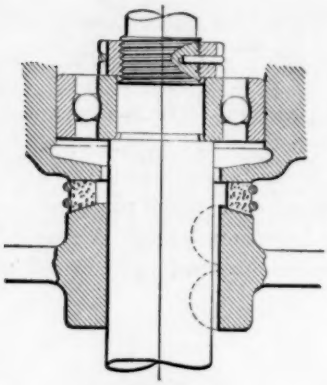

FIG. 43
BEARING CLOSURE—TAKE UP WEDGE FELT RING

23 Instead of having the felt ring hug the shaft it is tapered on one or both sides; the seal is then made entirely against the sides of the similarly shaped hub and boss.

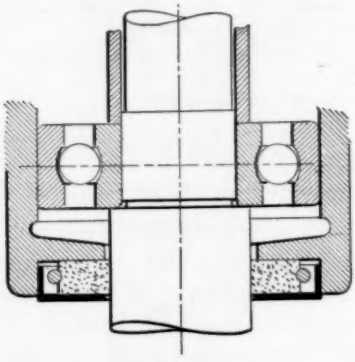

FIG. 44
A MODIFICATION

24 Whereas the two closures last shown were for insertion between the faces of a stationary boss and rotating hub, this modification is enclosed entirely within the one or other. The felt ring is set into a counter bore and held in place by a light metal cap that is sprung into place.

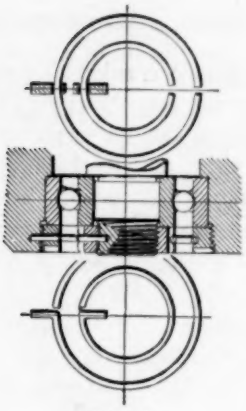

FIG. 45

A SIMPLE AND USEFUL NUTLOCK

25 Particularly with machinery that is subject to vibration it is necessary to lock firmly the nut that clamps the inner race. It is unsafe to rely on any form of a threaded lock; that also is likely to jar loose. Castellated nuts, etc., are unsightly and only permissible at the end of a shaft. The arrangement recommended consists of a split wire ring that is sprung into a groove turned circumferentially into the nut. A pin dropped into a hole drilled through the nut and partly into the shaft will be prevented from falling out by this guard ring. To permit of easily getting the pin out it is sometimes allowed to project and the ring is passed through a hole near the outer end of the pin. Not infrequently pin and ring are combined by bending the end of the ring over to act as the pin. The same arrangement is useful also when the nut is threaded on the outside to lock the outer race of a ball bearing, as shown.

CHAPTER VI

VARIOUS BALL BEARING MOUNTED AUTOMOBILE ELEMENTS TAKEN FROM CURRENT PRACTICE

1 As it was the earliest, so the gasolene driven automobile is still the predominant type.

2 The illustrations are taken from working drawings courteously placed at my disposal by builders of that type of touring and commercial car.

3 Beginning with the engine, the crankshaft, camshaft and subsidiary shaft bearings, such as those of the fan and pump, come under consideration.

BUILT UP CRANKSHAFTS

4 A decidedly interesting crankshaft is made by Smith & Mabley. At 1200 revolutions per minute, the eight 7 inch diameter by 6¼ inch stroke cylinders developed 190 horse power. The shaft is built up of similar units, all of which are clearly shown on Fig. 46.[1] Only the five main bearings are ball journaled. The shaft joints are placed directly under the inner races of the ball bearings. These joints are carried out as six jawed tooth clutches, the engaging faces of which are drawn together by body fitted bolts; the torsion effort is transmitted entirely through the jaws. The bolts, in conjunction with the shoulders on either side of the bearing seats, serve also to bind securely the inner races. Fig. 47 gives a fair idea of the appearance and size of the assembled shaft.

5 The same form of joint has been used in crankshafts by Noble, each unit consisting of one web and a half bearing seat; in his construction not only the main journals, but also those for the connecting rods were carried out as ball bearings. Noble, however, used a body free bolt with a tapered head fitting into a corresponding seat and drawn home by a similarly tapered nut. I understand from Mr. Noble that this principle for building up crankshafts has been used also on standard English locomotives for plain bearings.

6 A well thought out built-up crankshaft is that of the Moore Automobile Company, see Fig. 48 and Fig. 49. In this, each unit consists of a wrist serving as a journal of the usual plain type for the connecting rod end; this wrist forms a single forging with a flange at either end; these flanges carry circular bosses whose center line corresponds with that of the shaft main axis. As the bosses extend into and fit the bore of the main journal ball bearings from both sides, six body bound bolts connect and align successive units while securely binding the inner races between the web flanges. Moore uses very large bearings, as compared with current practice, for his cylinder diameters and lightens his crankshaft by liberally boring out the wrists and main journal bosses.

ONE PIECE CRANKSHAFTS

7 Of one-piece crankshafts the Stearns, Fig. 50, represents good mounting practice. The bore of the bearing must be large enough to permit threading it over the webs. This is a four cylinder crankshaft

[1]Fig. 46 to 76 inclusive will be shown at the Meeting. They were not prepared in time for publication.

with one central and two end bearings. The bore of the central ball bearing is large enough to pass over the webs to find its seat on the corresponding short wrist close up to one web. A narrow shoulder locates the bearing endwise. It is confined from the other side by a halved collar that fills the space to the other web; the halves of this collar are firmly bolted together. End crankshaft bearings are frequently selected of a smaller bore than the central ones as they need not be passed over webs; they must then be selected from a heavier series. In this case the designer preferred to use the same size bearings throughout. The difference in diameter of shaft and bore of end bearings was made up by bushes tightly fitted into the shaft and into the bearings. Structural simplicity and stiffness, with light weight of the crank casing was secured by making this of one piece instead of capping it, as is the more general practice; the endwise assemblage that this demanded is responsible for the bushes that carry the outer races of the central and right hand end ball bearings. The bores for these bushes permit the insertion of the cranks.

8 This same drawing, Fig. 50, contributed by the Stearns Company also shows its practice in camshaft mounting on ball bearings. The shaft case is integral with that for the cranks and open only at the ends for assemblage. With the exception of the coned end for the driving gear, the shaft is of uniform diameter throughout its length. The cams, pinion, and inner races of the ball bearings, of which there are five, are all clamped endwise from the end nuts by interposed tubular distance pieces. The bushing taking the outer races of the ball bearings are inserted merely to permit the endwise passage of the cams, the extreme radii of which are larger than the ball bearing semidiameters.

9 Means for getting the bearings to place over the webs are many and various; an interesting expedient, Fig. 51, due to French ingenuity, consists of cutting away a portion of the outer seat and then, when the bearing is in place, pushing in a correspondingly shaped liner to restore the circular outline and securing this by screwing it to the web. This example also shows the ball bearings applied to the shaft ends of the connecting rods.

10 To the employment of ball bearings for the main and the journals of gasolene engine crankshafts there is no known limit. A reproduction, Fig. 52, from this Society's Transactions for 1906, illustrates a crankshaft from French practice, each main journal of which has to carry a working load of 20,000 pounds at 450 revolutions per minute. The acceptance run involved trying out under 28,000 pounds load per journal for 14 hours at 450 revolutions per minute.

11 The connecting rod end presents a more difficult problem. The velocity of the journal is continuously varying with the angular position. In larger engines the inertia of a ball that can withstand the rather violent effect of the charge opposes this continuous change of speed so as to cause a serious interference with correct rolling. In Europe, where this use of ball bearings is of sufficiently long standing, experience has shown that this influence is negligible for engines of less than six inches cylinder diameter.

CRANKSHAFT BEARING SELECTION

12 The load imposed on crankshaft bearings is governed by so many complex factors that it is more practicable to base the selection of a particular type of bearing on a simple rule of thumb, the substantial reliability of which has been proved by experience. For the conditions obtaining in gasolene engines of the automobile and marine type, an average pressure of 300 pounds per square inch of piston area is assumed, and a bearing selected whose rated carrying capacity for steady load and speed corresponds to the total so arrived at. For the main journals, provided these are equi-distant on either side of the cylinder center, bearings having five-eighths of this capacity will answer; for a different relative location larger bearings, corresponding each to its location lever arm, must be selected. Such bearings have invariably proved sufficient for any size of engine for the main journals and on the connecting rods for cylinders up to six inches diameter, while often, too, bearings of three-fourths of this capacity have been found satisfactory. Experience has proved that motors of similar cylinder dimensions impose widely differing loads on their journals.

CHANGE GEARS

13 The automobile industry possibly more than any other shows clearly the universality of modern engineering and the obliteration of national lines. A case in point is that of the French Mors car which is being built in this country by the St. Louis Car Company. The 24 horse power gear case, Fig. 53, is a good example in the mounting of the now almost universal sliding gear type. The ball bearing that carries the squared driving shaft at one end is confined endwise both as to its inner and outer race; a shoulder clearance at the inner end of this shaft makes certain that no end-thrusts are thrown on this bearing beyond those due to the shifting of the gear-spool; the inner race is journaled in a bronze-bush in the jaw driven bevel gear whose hub is carried in two ball bearings, the rear-most of which takes also the

thrust of the bevel drive. Of the three ball bearings on the back gear shaft only two receive radial load, since the one that is directly behind the bevel gear is quite free as to its outer diameter, so that its full carrying capacity is available to take care of the bevel gear thrust. The cross countershaft also carries four ball bearings of the radial type, two of which, however, are again freed of all radial load, and so sustain only the outward thrust of the bevel gears. The proper meshing of the bevel gears is arranged for by the endwise adjustability of the bearing mountings; definite, single position locks for the adjusting nuts make this practice reasonably safe from maladjustment later on by the repair hand, or, worse still, the chauffeur, anxious to justify skilled mechanics' pay by tinkering with the adjustments.

14 The various ball bearings are not mounted directly in the aluminum case, but in interposed bronze shells. This is a practice surviving from the earlier days when aluminum castings were rather too soft to permit the concentration of journal loads on the rather narrow areas corresponding to the ball bearing races. Many builders find it quite safe to dispense with these bushings, even where crankshafts involve a rather severe hammering load. A case in point is the French Berliet sliding gear of Fig. 54, by the American Locomotive Company, for 40 and 60 horse power. In this all of the bearings, with the exception of those at the sprockets, are directly mounted without interposed liners. End-thrusts are carried on ball bearings of the collar type; an exception is the thrust due to the driving bevel pinion, which is taken on an adjustable hardened button. The driving fit of the inner race of the various ball bearings is relied on; so long as such fit is initially secured by careful workmanship and its permanence under the peening effect of the more or less vibratory load is assured by sufficiently hard shaft material, this practice is safe enough. Actual binding between shoulders and nuts or their equivalents is nevertheless to be recommended as a wise reënforcement and safeguard.

15 A decidedly good design as to mounting is found in Fig. 55, a change gear contributed by the Locomobile Company of America. Every inner race is securely bound endwise between substantial shoulders and locked nuts or interposed distance pieces. Every shaft that is held against lengthwise shifting is so held in both directions at one bearing only. The possibility of imposing uncontemplated end-thrusts on any bearing by setting up any nut too far is guarded against, since the design will not permit any such maladjustment, either because the nuts come up solid or are provided with one-position locks. The end-thrust of the bevel gearing is taken on the

rear member of each pair of radial bearings, its housing seat being sufficiently cleared radially to ensure that.

16 The drawing, Fig. 55, also shows an employment of radial ball bearings not previously referred to. The shifter fork, recognizable at the entering end of the driving shaft, is provided with small ball bearings, the outer races of which act directly as rollers.

CHANGE GEAR AND CLUTCH

17 The Winton Company's sliding change gear case and multiple disc clutch mounting is represented by Fig. 56. In this, two methods of securing the inner ball bearing race are shown—one the nut recommended by the writer and the other a split washer or collar dropped into a groove in the shaft; as the latter device cannot provide any endwise clamp the integrity of the shaft fit must be relied on.

18 The Pierce "Great Arrow" change gear of Fig. 57, shows that the dictates of experience for reliable ball bearing use have been carefully incorporated. All inner races are driven on their seats and also clamped between shoulders and nuts. All outer races are slip fits in their seats and are free endwise except where the ball bearings are to secure a shaft or spool lengthwise; this office is always assigned to only one bearing on a shaft, so that no deflections of either housing or shaft, or variations in length due to temperature changes, can bring about unpremeditated end-thrusts; as this arrangement at the same time allows considerable latitude in the lengthwise relationship of shoulders on shaft and housing, shop economy as well is promoted.

19 The general scheme of the Matheson Company's gear case, Fig. 58, is somewhat similar to that of the Mors of Fig. 53; in both the thrust of the direct drive bevel pinions is taken on a radial bearing, free circumferentially. The Matheson designer, however, prefers to take the secondary bevel pinion thrust on a central ball at the end of the shaft. For the first time, so far as heretofore shown, not only radial load, but also the thrust load due to the cross shaft bevel gears is taken on the same radial bearing; this double load is responsible for the rather large dimensions of these bearings.

20 The various change gears so far as shown were all of the type having a shaft whose one end was journaled in a continuous spool. Owing to the space limitations with the usual design this shaft is generally journaled in a bronze bush in the spool.

21 In Fig. 59, contributed by the builders from Nordyke and Marmon's change gear practice, this end is mounted in a ball bearing; the design is so managed as to admit a bearing of sufficient size. The

usual thing is either to mount the ball bearings directly in the case or in lining bushes. The end view, Fig. 60, shows a departure for which the makers claim certain advantages: Two bronze plates are dropped into milled slots in the aluminum case; these plates facilitate the accurate spacing, alignment, and machining of the drive and reverse shaft bearing seats; they relieve the aluminum case of strains which are taken up in the plates.

22 The Knox Automobile Company's gear case, Fig. 61, is of particular interest, since a case that has a record of over 30,000 miles to its credit with all bearings in perfect order, is good proof, not only of the reliability of ball bearings, but of the suitability of size selection and of the correctness of design of mounting and arrangement.

TRUCK GEAR CASE

23 That ball bearings are equal to the conditions of the heavier commercial vehicles as well as to those of the touring car type heretofore shown may be left to the evidence of Fig. 62, a gear case used by Mack Brothers in the chassis on which they mount not only their sightseeing bodies, but also those for their 2 to 10 ton trucks. Bearings of the radial type are used throughout and carry the radial loads as well as the thrusts of the bevel gearing. Since 1905 there have gone into use some 63 of these cars. That a close grained cast iron makes a very satisfactory liner is shown by this case, in which that material is interposed between the ball bearings and the aluminum housing. Convenience of access from underneath is provided by holding the liners up by encircling stirrups, so that the entire case cover can be dropped. The whole design commends itself favorably to the writer as in line with his preference, as an old machine tool designer, for always substituting a separate tooth clutch engagement for sliding gears. The universally favorable experience with clash gears is only another instance of the upsetting of traditions and supposedly inviolable rules of experience. What sane designer outside of the automobile field would, for instance, submit his gears to such stresses and speeds as are standard in automobiles and under most adverse conditions? Yet such gears work, work well and certainly last well also.

24 A good example along more conventional automobile lines is that of Fig. 63, of a 35 horse power side chain driven, heavy truck change gear. All of the journals, including the reversing idler gear, are ball bearing. All bevel thrusts are taken on separate, compensating seat ball collar bearings. The designer has evidently very carefully considered the loads imposed on the different journals at

the speeds most likely to be demanded by the character of the truck service and has selected his ball bearings accordingly. American designers would, as a rule, be more apt to use fewer different sizes of bearings and promote shop economy by the employment of fewer tool changes at somewhat higher initial bearing cost for a few larger sizes.

CHANGE GEAR BEARING SIZE SELECTION

25 The conditions under which the ball bearings have to work in change gears are so varied that it is practically impossible to give universally adequate directions for a proper selection of sizes. The location of the case on the chassis, whether near the motor or close to the rear axle, the mode of suspension and other elements which will greatly affect the severity of the road hammer, the relative use of the various speeds as determined by the character of the country, as well as that of the drivers, even the uncertainty as to the power actually transmitted, all are factors which should be, but which cannot be, taken into quantitative consideration. The best guide must be the experience gained by the bearing manufacturer in carefully following up the performance of various cars: while he can place that experience at the disposal of interested inquirers in the shape of definite suggestions for definite submitted data, the inquirer himself generally prefers to make out at least a first design. It may be safely said that, as a rule, bearings of the medium series will answer for gear cases where such hearings are to be mounted directly on the shafts; it is the shaft diameters that will then usually compel sufficient size.

26 Where bearings are mounted on a spool or hub through which a shaft passes, the greater size consequent on the larger bore will usually make a selection from the light weight series practicable. Exceptions are frequently encountered where the bearings are to take the end thrust of bevel gears, as for instance those mounted on the sleeves of the differential gears; here usually a light weight bearing will answer for the non-thrust side and one of corresponding bore from the medium weight series for the thrust side to take combined thrust and radial load. If thrust and radial loads are taken in two separate radial bearings these may be often both taken from the light weight list. Where bearings of the collar type are preferred to take the bevel gear thrust, it will generally do to select a bearing whose bore will correspond to the contemplated location. Bearings of the heavy weight series are but rarely required; their use is generally due to a desire on the part of the builder for great excess in load capacity.

SPROCKET BEARINGS AND SIZE SELECTION

27 A single example of good design in sprocket mounting taken from the practice of the Locomobile Company and shown in Fig. 64 will do. The principles of mounting are not different from those laid down for other elements. To mount the bearings as nearly in line with the chain-pull as possible is always advisable. A safe guide to size selection will usually be found in the demands of the shaft as to bore and response to the extra stresses of loose and slapping chains by making the selection from the heavy weight series.

REAR AND FRONT WHEEL DESIGNS

28 Designs that are very good are reproduced in Figs. 65 and 66 from the practice of the Locomobile Company. The inner races of the bearings are driven on and are clamped by the use of the single castellated end nut; an interposed tubular distance piece bridges the gap from the outside to the inside bearings and so serves to bind both races. Flanges at either end of this distance piece extend both inward and outward to the axle and the bub; these are an ultra conservative designer's safeguards for supporting a wheel should the bearings fail. A large washer bridging the annular space between the inner and outer race of the front bearings will keep out much of the grit, etc., that would otherwise get into the bearings should the hub cap be knocked off when trying conclusions with some passing wheel. All thrust in either direction is taken on the inner bearing which is, as to its outer race also, firmly clamped endwise; the outer race of the other bearing is free and therefore subject to no end-thrust.

29 The St. Louis Car Company's "Mors" rear hub is shown in Fig. 67. Thrust in one direction is taken on the outer bearing, in the other on the inner. The inner face of each outer race fetches up against a shoulder in the hub when taking thrust. Provided that the tubular distance piece on the stub is always a safe trifle longer than the distance between the thrust shoulders in the hub, this design is safe. Should the tube be short, then screwing up the end nut on the axle will set up end-thrusts in the bearings which may easily be so high that the latter must very quickly fail.

30 The influence of the relative location of the bearings and the center of the wheel tread on the size of the bearings is clear from a comparison of Fig. 65 already described and this Fig. 68 of the "Great Arrow" front hub. In this latter a location of the tread more directly in line with the inner bearing throws more of the load on that and so compels the employment of a relatively larger bearing for this place.

The necessary difference is, however, not quite that shown, part being due to personal preferences. Both are ample as to size.

31 A second direct axle driven rear hub is that of Fig. 69, again from the "Great Arrow," which throws the entire wheel load on to a single liberal ball bearing that also takes all wheel thrusts.

32 A floating axle, jaw driven, rear hub mounting is contributed from the Marmon Car as Fig. 70. The wheel runs on two bearings driven on to the axle tube and securely clamped as to their inner races by nut and distance tube. Both outer races are entirely free endwise, so that the wheel thrusts do not affect the hub bearings, but are transferred through the shaft connection to be taken care of elsewhere, as referred to later in dealing with a few typical bevel-gear drives to rear axles.

33 A favorite German heavy truck front hub and steering pivot is that of Fig. 71 taken from a truck of 10 tons dead weight to carry a load of 5 tons. One of these has demonstrated its qualities in the decidedly heavy work incident to a shop removal from Berlin to the suburbs in the transfer of much heavy machinery under hurry up conditions. If proof of the preëminent advantage of the modern motor truck were needed, this work conclusively demonstrated it, in active and forced day and night competition with horsedrawn vehicles.

34 While the power loss due to friction at the steering pivot can never be serious, since, though with plain steps the friction is high, the speed and distance are slow, nevertheless the substitution of a ball step greatly facilitates the ease of handling and provides that responsiveness of the steering wheel that the man at the helm values highly and that gives him the impression that his vehicle is a sentient being, rather than a mere inert piece of mechanism.

BEVEL DRIVEN REAR AXLES

35 A typical arrangement is that of Fig. 72 taken from the Pierce "Great Arrow." Both radial and thrust load due to the bevel pinion are taken on the same radial bearing, but when it comes to the bevel gear, the designer prefers to take these separate loads on separate bearings. A collar type of ball bearing is therefore placed behind the radial bearing on the thrust side of the differential hub. The spherical compensating seat for the stationary ball plate permits the employment of a more convenient, smaller bearing than was general in older practice using flat, non-compensating races.

36 The Nordyke and Marmon bevel gear driven rear axle of Fig. 73 differs from that just described in no essential arrangement of the

bearing mountings. The axle is, however, of the floating type with the wheel bearing relieved of all thrust loads. These are transferred to and through the axle so that the inward thrust is taken up on the collar ball thrusts on the opposite side of the differential, while the outward thrust is taken up on the collar ball thrust on the same side of the differential.

37 Notwithstanding that the radial form of annular bearing of the uninterrupted (dwf or hb) race cross section is taking wheel thrusts in many cars besides those illustrated, there are still many designers who hesitate to be convinced. The construction last described meets their fears by transferring all thrusts to the central, collar type, ball bearings.

HUB AND AXLE BEARING SELECTION

The remarks about bearing selection made in connection with change gears apply with equal force to those for rear axle bevel drives.

38 For front and rear hubs, where these are supported on two bearings, it will usually be safe to consider one third of the entire load of a car plus passengers at 150 pounds each as coming on one wheel; about 10 per cent of this taken off for a front wheel and 10 per cent added for a rear wheel will sufficiently allow for the greater rear loading.

39 A bearing pair should be selected whose combined steady load and speed rating should be not less than one half greater than this figure, provided that the center of the wheel tread is placed about twice as far from the center of the outer bearing as from that of the inner one and provided further that the rated capacity of the outer bearing be not less than two-thirds that of the inner. Either bearing may be arranged to take the thrusts, but it is always preferable to take both thrusts on the same one. Shifting the tread center will demand a larger bearing for the one toward which the shift is made; for the extreme location directly in line with the bearing center, the rated capacity of that one should equal the full one and one-half wheel loads, as determined above.

40 The thrusts had then best be taken on the outer bearings. Where a single bearing carries the entire wheel load, the size selection will be the same as governs when the tread is located in line with the inner bearing. Also, as a rule, bearings of the light weight series should not be employed in wheels even though their rated capacity is sufficient; the road shocks call for larger balls than are usually found in the light weight bearings, unless those of quite abnormal bore should be chosen.

41 It is understood that this is but a rule of thumb, in which no constants for the varying influences of diameter of wheel, length of wheel base, radius of turning curves, speed, etc., are recognizable. The assigning of proper values to these elements is not possible, or rather not as yet.

42 On the other hand, experience on all sorts and conditions of roads and road apologies in the United States and Europe has proved that these directions give as good a selection as can be tentatively made. It should naturally always be carefully scanned in its applicability to each individual case in the light of analogous experience. It is to be borne in mind that these general directions for hub bearings apply to pneumatic tires, and that for solid rubber, wood, steel, etc. the selections should be raised one-third.

SOME MINOR MECHANISM MOUNTINGS

43 Of camshaft bearings the Stearns arrangement, previously described in connection with the crankshaft and Fig. 50, may serve as a good example.

44 The Moore camshaft and cross driving shaft of Fig. 74 is carried on two ball bearings. More interest (no pun intended) but nevertheless ours also, attaches to the centrifugal pump bearing shown at the right hand end of this Fig. 74. At first supposed to be beyond the possibility of ball bearing on account of the difficulty of preventing leakage of water into the ball bearing without the use of a stuffing box of such friction as to render the ease of running of the ball bearing illusory, success was won with the frictionless, grease packed, groove closure substantially on the lines of Fig. 41 and by pressing a small packing collar to its seat under a light spring load.

45 The universal coupling, as we have it, or Hookes joint of our British cousins, or Cardan of the French designer does not, at first, seem to offer much room for ball bearings. Yet the use of four, one at each pin, has been amply justified by results. Fig. 75 illustrates the Moore Automobile Company's arrangement at the end of the change gear box. The ball bearing here justifies its employment not so much by power saving incident to friction elimination, since, though pressures are fairly heavy the speed and traverse are but inconsiderable, but rather by immunity from frictional binding and absence of wear when suitably enclosed. In this particular case also the usual rough and grinding action of the telescoping joint is replaced by a rolling of two of the ball bearings in a slot seat. This Fig. 75 is worthy also of a little more detailed study for the change gear that it

discloses. It presents no general features for mounting that have not already been discussed.

46 Ease of operation of the Stearns expanding flywheel clutch is promoted as shown in Fig. 76. The outer ends of each of the shafts extending from the center terminate in eccentrics. The outer races of a ball bearing held in a suitable case serve as the eccentric strap. Rotation of the shafts and eccentrics expands each brake band through an interposed adjustable toggle to firmly grip the flywheel.

CHAPTER VII

CONCLUSION

1 Although the idea of substituting rolling for sliding friction is nearly as old as mankind itself, dating from the time when man, condemned to labor, applied his observations of the relative ease of rolling an approximately round stone down on his enemy as against sliding a flatter one, to an easing of that labor, it is only within a few years that material progress has been made.

2 In the preceding pages the matter was dealt with from the standpoint of the usefulness of the ball bearing to the self-propelled vehicle, that necessarily limited the discussion to just enough of general matter to make intelligible and reasonable the various directions and selections for type selection, size determinations, and mounting arrangements, culminating in examples from standard practice of various firms that courteously placed their drawings at the author's disposal.

3 The time and space available in the Society Meetings and Transactions and the good nature of an engineering audience further restricted the scope. As much has been omitted that some might wish to have considered, these conditions must serve in extenuation. A great deal of matter on the behavior of ball bearings of many different types under various conditions has been accumulated and is still being added to. Much work in the trying out of various materials, on the influence of their chemical and physical characteristics, on the influence of heat treatment, on methods and apparatus for testing, has been done, is being done, and still remains to be done. The author will take much pleasure, as occasion may serve, to make such contributions along these lines as may appear of general interest and will take particular pleasure in answering now or later any demands for information on any phase of interest.

APPENDIX

BALL BEARINGS FOR VARIOUS LOADS

Reports from The Central Laboratory for Scientific Technical Investigation

By PROFESSOR STRIBECK, NEUBABELSBERG NEAR BERLIN

TRANSLATION FROM THE GERMAN WITH RÉSUMÉ AND NOTES, BY HENRY HESS, PHILADELPHIA, PA., MEMBER OF THE SOCIETY

About two years ago[1] the Central Laboratory had occasion to take up the design of ball bearings for the heavier loads, in the interest of the German Small Arms and Ammunition Factories of Berlin (Deutsche Waffen- und Munitionsfabriken). At that time there were not available sufficient data on either the permissible loading of balls, nor yet on the frictional values of ball bearings. Consequently the first task was the experimental determination of such design data.

2 The more important results of this work have in the meantime been confirmed by experience in practical work.

3 Since these results are applicable not only to ball bearings, but also to a much wider technical domain concerned with the contact of elastic bodies, a detailed report appears advisable.

OCCURRENCES AT THE PLACES OF PRESSURE

4 The inquiry into the permissible loading of balls includes many problems. From the consideration that the occurrences at the places of pressure are essential to the behavior of balls and races, the first problem is to determine these in their dependence upon the load.

5 Hertz, in his work "On the Contact of Elastic Bodies" (Ueber die Berührung elastischer Körper), examined the general case of two elastic bodies of any shape when pressed together. The admissibility of his deductions is dependent upon the following assumptions:

[1] This report was written in 1900.

To be presented at the Indianapolis, Ind., Meeting (May, 1907) of The American Society of Mechanical Engineers, and to form part of Volume 28 of the Transactions

a The bodies may be in contact only at small parts of their surfaces.

b There must be no forces except such as act normally upon the surfaces in contact. This would be the case, as stated by Hertz, if the surfaces in contact were perfectly smooth.

c The materials must have proportional limits, and at the same time the deformations corresponding to the proportional limits must not be exceeded.

d The bodies must be homogeneous.

6 For the case of the two balls, chiefly considered in this work, having radii r_1 and r_2, equal elastic moduli α, and for which the factor of lateral contraction may be assumed as $m = 10/3$, Hertz has it that:

a The distance $\frac{\delta}{2}$ through which the bodies approach one another normally to the pressure surface under the load P; that is, the compression is

$$\frac{\delta}{2} = 1.23 \sqrt[3]{P^2 \alpha^2 \frac{r_1 + r_2}{r_1 r_2}} \qquad [1]$$

b The radius of the pressure surface, is

$$a = 1.11 \sqrt[3]{P \alpha \frac{r_1 r_2}{r_1 + r_2}} \qquad [2]$$

c The maximum pressure, which acts at the center of the pressure surface, is

$$p_o = 0.388 \sqrt[3]{\frac{P}{\alpha^2} \left(\frac{r_1 + r_2}{r_1 \quad r_2} \right)^2} \qquad [3]$$

From this it follows that the pressure p_o is 1.5 the average pressure.

7 But the central elements of the pressure surfaces are not only compressed normally to the surface, but also in the other two directions. For circular pressure areas the principal stresses in the tangential plane are, according to Hertz, $(0.5 + 1/m)$ times the normal stress, with $1/m = 0.3$, and therefore $0.8\ p_o$.

8 Hertz carried out a number of experiments with glass in order to prove the agreement between practical results and his deductions. He showed, by pressing a glass lens against a plane disc of similar glass, that the diameters of the pressure surfaces increased as the cube roots of the pressures. To determine the influence of the elastic modulus, he pressed a steel lens against the plane surfaces of various metals, but encountering difficulties of observation he gave up the experimental proof.

9 Later, Auerbach by also pressing lenses against plane discs using three varieties of glass and one mountain crystal and measuring the compression areas, confirmed the relation of the compression area, diameter, load, and the lens curvature radius as previously investigated by Hertz.

10 His experiments, however, with various curved bodies of the same material gave no agreement of pressure at the elastic limit. According to Hertz, passing the elastic limit in glass or other similar brittle substances first resulted in a circular crack closely following the edge of the pressure surface. The pressures causing these cracks were found to be dependent upon the curvature of the lenses, and invariably proportional to the cube roots of the ball surface diameters. For ball and disc the load at the elastic limit was not found to be, in accord with Hertz's formula, proportional to the square of the diameter, but proportional to the diameter. No conclusive explanation has yet been found for this phenomenon. Hertz himself did not consider it out of the question that the beginning of the elastic limit was dependent upon subsidiary influences, since he says: "The deductions greatly need an examination by practice, for it might be that actual bodies only remotely agree with our fundamental supposition of homogeneity. It is well enough known that the properties near the surface, which are those that here chiefly concern us, are frequently very different from those in the interior of the bodies."

11 So far there has been no basis from which to determine whether with metals also, the pressure at the elastic limit is dependent upon the surface curvature; yet this problem is important enough in general, and more especially so for the designer of ball bearings. Its solution will define the relation of the permissible load to the curvature of the bodies in contact. The clearing of this problem, at least for hardened cast steel, was therefore a prime consideration. It was also to be considered that since Equation 3 gives, for ball on disc,

that $$\frac{1}{r_a} = 0 \text{ and } 2\,r_1 = d$$

$$p_0 = 0.388 \sqrt[3]{\frac{4\,P}{\alpha^2\,d^2}} \qquad [3a]$$

with $$\alpha = \frac{1}{2{,}120{,}000} \text{ (by trial)}$$

this gives

$P =$	d^2	$2\,d^2$	$3\,d^2$	$4\,d^2$	$5\,d^2$	$10\,d^2$	$50\,d^2$	$100\,d^2$
$p_0 =$	10,160	12,810	14,660	16,140	17,380	21,900	37,450	47,180 kg.cm.^{2}

12 As a matter of fact this equation holds good only so long as the limit of proportionality of the bodies is not exceeded at any point. For the center of the pressure surface, where the greatest pressure exists, the chief stresses may be calculated by the Hertz method. It is only the largest one, normal to the surface, which concerns us and which amounts to 0.52 of the stress which p_0 alone would cause, since the existence of three main forces p_0, $0.8\ p_0$ and $0.8\ p_0 (1 - 2 \times 0.8 \times 0.3)\alpha\ p_0 = 0.52\ \alpha\ p_0$.

13 If the elongation be accepted as a measure of the stress the material is subjected to, the limit of proportionality is in this case reached with a pressure which is

$$\frac{1}{0.52} = 1.92$$

times as great as that found by compression tests on a prismatic object.

14 It is assumed, of course, that the availability of Equation 3 for the proportionality is confirmed by experience. Two compression tests made with ball steel cylinders hardened in water, gave a limit of proportionality of 9000 kg. per 1 cm.^{2}

15 For a ball and disc of hardened ball steel, Equation 3 gives the load at the beginning of the limit of proportionality in round figures $P = 5\ d^2$.

16 It is not to be expected that these relations hold also for greater loads. If one were, however, to take the permissible loads in ball bearings low enough not to exceed the elastic limit, that would be tantamount to giving up the use of ball bearings for heavy loads. This gave as a further problem the determination of the deformations under higher loads for which the third assumption of the Hertz equation does not hold, and to measure of the elastic compression as well as the permanent set.

EXPERIMENTS ON THE COMPRESSION OF HARDENED STEEL BALLS AND DISCS

17 As previously mentioned, for the few experiments that were made to prove the Hertzian equations, the diameters of the compression surfaces were measured. This proceeding is not applicable to the present investigation, as it does not give any information on the permanent deformation. Aside from this it was, however, not practicable after each of the many loadings to separate the test pieces for a microscopic examination of the pressure surfaces. The difficulty was increased by the need of measuring the elastic recovery, which is

very much in evidence with hardened steel. For these reasons the compressions of the test pieces were measured; Hertz's Equation 1 is applicable to these.

18 In accordance with their object, the experiments were made on hardened cast steel. This material is peculiarly suitable to prove Hertz's equation since its limit of proportionality is high, so that relatively heavy loads may be employed.

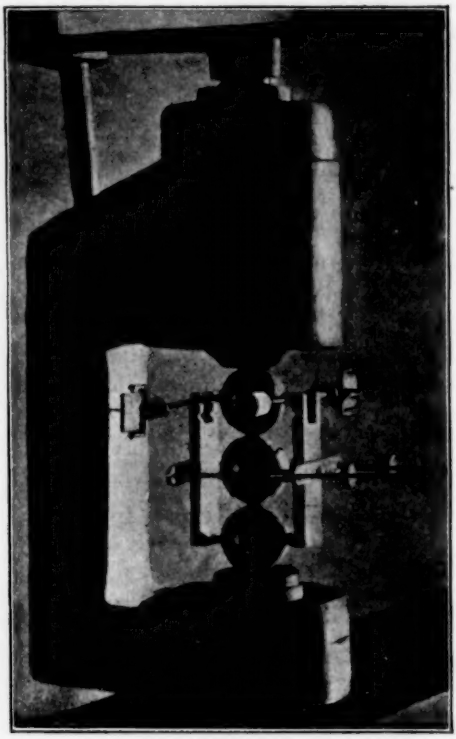

FIG. 1

19 On the other hand, many difficulties were to be expected in the determination of the compressions beyond the elastic limit. The compression is in a large measure dependent upon the hardness of the test-piece, and the necessarily large number of test pieces would scarcely be uniformly hard. To get good average results, each test series would have to be oft repeated with new specimens. Happily, the balls furnished by the German Small Arms and Ammunition

Factories varied but slightly in hardness, so that no inequalities of moment were found in compiling the results.

20 Hertz's second assumption that "there must be no forces except such as act normally upon the surfaces in contact," is not complied with by the older procedure of pressing a ball against a flat plate, since, with the exception of those at the center, the surface elements in contact are subject to different stresses and, therefore, tend to glide over one another, which they could do only by overcoming friction. But this second condition is fulfilled when balls of similar material and size are pressed together. This condition was, therefore, investi-

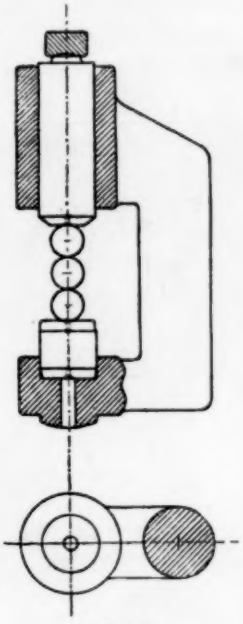

FIG. 2

gated first. Later on balls were also pressed against flat plates. This gave two groups of test results, each of which could serve for the determination of the dependence of the load at the elastic limit upon the ball diameter.

21 The compression of the test pieces was measured with a mirror apparatus as designed by Martens. For the first group of experiments three balls were set one on the other. The knife edges of the measuring bars were attached at the half height of one outer ball and the knife edges of the mirrors were similarly attached to the other outer ball as shown in Fig. 1.

22 The measured distance, therefore, included two pairs of compression surfaces, so that the compression of two test bodies was measured. This permitted the determination of smaller impressions than with a single arrangement, which was particularly important for the very small permanent sets; this further permitted the reduction of the test series in that the measured values themselves corresponded to the average for two test pieces. The handling of the larger measuring bars was also much easier than that of the shorter ones for the single arrangement.

23 Dr. Amsler, with whom I talked about my intention to superpose these balls for measurement of the deformation, and who was, therefore, induced to take the matter up after some time, supplied me with an appliance substantially as shown by Fig. 2.

FIG. 3

24 The two outer balls were located in this holder by small conical depressions. The center ball was aligned with the outer ones by means of one straight and one angular guide, Fig. 3. Amsler provided a pair of pliers with similarly formed jaws for the simultaneous insertion of these balls, which was particularly useful with small balls.

25 To secure a firm attachment of the knife edges to the outer balls, small tubes of brass were cemented to the latter against which the knife edges were set. Double readings were taken, one on each side of the balls.

26 In the tests of balls on plates, a cylindrically turned disc was set between the two balls as shown by Fig. 4. Its thickness was equal to or greater than a ball radius. These discs were of the same material and were hardened in the same way as the balls.

27 Deformations were magnified 500 times, and the observed compression therefor corresponded to the average compression of one test piece pair under a magnification of one thousand. The appa-

ratus described was used in a 5 ton Amsler compression testing machine.

28 The test pieces were alternately loaded and released. This was repeated for each load value until the compression was constant. At first the load on the upper piston of the ball holder was taken off completely so that the only weight on the balls was that of this piston. It was found, with the smaller loads under which permanent com-

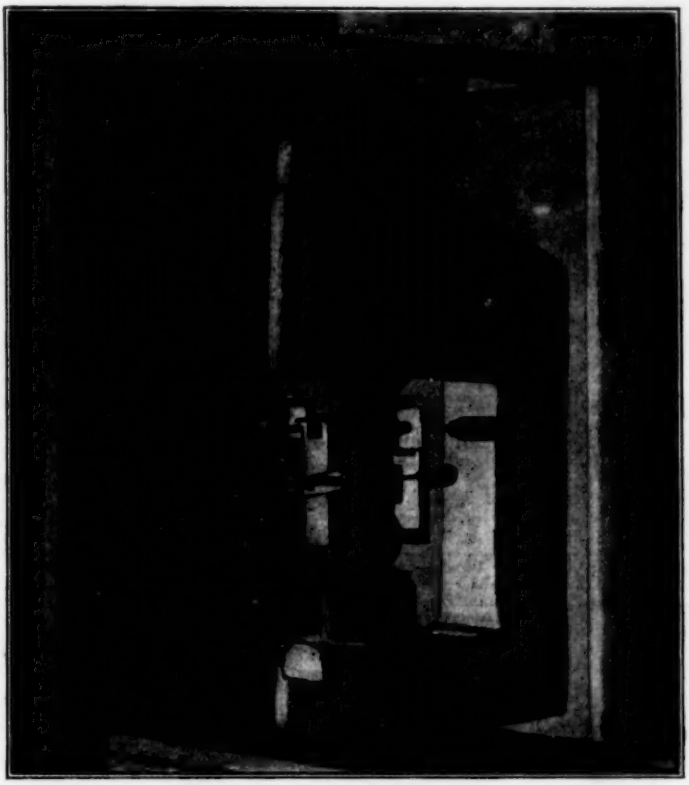

FIG. 4

pressions could not be definitely proved that the test values were in almost absolute accord with those found by calculation.

29 Since such complete release of the load readily caused disturbances, the lower load limit was, in view of the experience just cited, taken higher, generally 20 or 50 kg. The compression due to this load is determined by Equation 1.

30 The tests were carried out on balls ranging from $\frac{3}{8}$ to $\frac{9}{8}$ English inches. The results are given in Table 1 and 2.

TABLE 1

3 BALLS OF $\frac{1}{4}$ INCH IN LINE

By equation 1 : $\frac{\delta}{2} = 0.00012025 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	by equat'n 1	3.26	5.18	8.22	10.78	13.06	15.15	17.11	18.96	20.73
	observed ...	3.32	5.41	9.17	11.82	14.62	17.31	19.71	22.21	24.54
	averaged ...	3.32	5.42	8.87	11.90	14.66	17.31	19.84	22.30	24.65
See Fig. 6 and 7										
δ_b Set	observed ...	0.06	0.27	0.95		3.01		5.30		7.80
	averaged ...	0.07	0.27	0.90	1.74	2.74	3.85	5.06	6.38	7.80

3 BALLS OF $\frac{1}{2}$ INCH IN LINE

By equation 1 $\frac{\delta}{2} = 0.0001092 \sqrt[3]{P^2}$

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	by equation ..	4.71	7.47	9.79	11.86	13.76	15.54	17.23	18.83
	observed	4.83	7.81	10.33	12.83	14.98	17.33	19.14	21.14
	averaged.. ..	4.85	7.85	10.49	12.88	15.10	17.25	19.28	21.21
δ_b Set	observed....	0.18	0.51	1.34	1.72		3.09		4.68
	averaged.....	0.18	0.56	1.10	1.72	2.45	3.26	4.12	5.06

3 BALLS OF $\frac{3}{4}$ INCH IN LINE

By equation 1 $\frac{\delta}{2} = 0.0001014 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δTotal	by equation .	2.75	4.37	6.94	9.09	11.01	12.78	14.43	15.99	17.48
	observed	2.78	4.44	7.14	9.45	11.65	13.62	15.49	17.42	
	averaged	2.78	4.43	7.13	9.51	11.65	13.63	15.53	17.35	19.08
δ_b Set	observed.....	0.05	0.11	0.39	0.66	1.01	1.51	2.17	2.81	
	averaged	0.05	0.11	0.35	0.68	1.14	1.63	2.19	2.81	3.45

3 BALLS OF $\frac{7}{8}$ INCH IN LINE

By equation 1 $\frac{\delta}{2} = 0.0000954 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δTotal	by equation .	4.11	6.53	8.55	10.36	12.02	13.58	15.05	16.45
	observed	4.11	6.68	8.86	10.82		14.39		17.72
	averaged	4.12	6.62	8.79	10.76	12.59	14.31	16.00	17.58
δ_b Set	observed		0.22	0.50	0.85		1.61		2.69
	averaged ...		0.22	0.46	0.78	1.12	1.52	2.00	2.48

3 Balls of $\frac{1}{2}$ Inch in Line

By equation 1 $\frac{\partial}{2} = 0.0000907 \sqrt[3]{P^2} = 1814$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
∂ Total	by equation ..	3.91	6.20	8.13	9.84	11.42	12.90	14.30	15.63
	observed	3.93	6.22	8.19		11.75		14.96	16.44
	averaged	3.91	6.22	8.23	10.09	11.79	13.38	14.92	16.38
∂_b Set	observed			0.23		0.64			1.78
	averaged		0.15	0.30	0.55	0.79	1.10	1.42	1.80

3 Balls of 1 inch in Line

By equation 1 $\frac{\partial}{2} = 0.0000867 \sqrt[3]{P^2} = 1734$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
∂ Total	by equation ..	3.74	5.39	7.77	9.42	10.93	12.34	13.67	14.95
	observed	3.74	5.94	7.86	9.56		12.67	14.11	15.50
	averaged ...	3.74	5.94	7.84	9.59	11.21	12.70	14.13	15.50
∂_b Set	observed		0.12	0.22	0.39		0.70		1.28
	averaged		0.10	0.21	0.37	0.55	0.77	1.00	1.25

3 Balls of $1\frac{1}{2}$ Inch in Line

By equation 1 $\frac{\partial}{2} = 0.0000834 \sqrt[3]{P^2} = 1668$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
∂ Total	by equation .	3.59	5.70	7.47	9.05	10.50	11.86	13.14	14.37
	observed	3.60	5.80	7.51	9.24	10.74	12.20	13.45	14.83
	averaged ...	3.59	5.70	7.52	9.20	10.75	12.18	13.53	14.83
∂_b Set	observed.....		0.06	0.15	0.22	0.38			0.90
	averaged		0.08	0.15	0.25	0.37	0.52	0.70	0.90

TABLE 2

Flat Disc Between Two $\frac{1}{2}$ Inch Balls

By equation 1 $\frac{\partial}{2} = 0.0000954 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
∂ Total	Hertz.....	2.59	4.11	6.53	8.55	10.36	12.02	13.58	15.04	16.45
	observed	2.64	4.15	6.62	8.57	10.54		14.18		17.59
	averaged	2.60	4.14	6.67	8.86	10.82	12.64	14.32	15.91	17.44
∂_b Set	observed		0.18	0.48	0.88	1.29		2.57		3.78
	averaged		0.18	0.48	0.86	1.33	1.86	2.48	3.12	3.81

Flat Disc Between Two ½ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000867 \sqrt{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δ Total	Hertz	2.35	3.74	5.92	7.77	9.42	10.93	12.34	13.68	14.95
	observed	2.37	3.78	6.04	8.04	9.68	11.40	12.77		15.60
	averaged	2.35	3.76	6.07	8.03	9.80	11.41	12.98	14.45	15.75
δ_b Set	observed		0.12	0.31	0.63	0.80	1.20	1.48		2.26
	averaged		0.12	0.33	0.60	0.89	1.21	1.6	2.00	2.46

Flat Disc Between Two ⅜ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000835 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	50	100	200	300	400	500	600	700	800
δ Total	Hertz	2.19	3.47	5.51	7.22	8.74	10.14	11.45	12.69	13.84
	observed	2.27	3.68	5.70	7.47	9.03	10.43	11.78	13.01	14.31
	averaged	2.19	3.50	5.64	7.40	9.04	10.54	11.93	13.23	14.46
δ_b Set	observed			0.18	0.39	0.62	0.78	1.08	1.16	1 44
	averaged			0.23	0.44	0.64	0.85	1.13	1.39	1.63

Flat Between Two ¼ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000720 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δ Total	Hertz	3.10	4.92	6.45	7.81	9.07	10.24	11.34	12.40
	observed	3.12	5.04	6.63	8.03	9.44	10.56		12.90
	averaged	3.11	5.02	6.59	8.03	9.40	10.60	11.75	12.87
δ_b Set	observed		0.09	0.18		0.41			0.90
	averaged		0.10	0.21	0.34	0.49	0.61	0.79	0.95

Flat Disc Between Two ⅛ Inch Balls

By equation 1 $\frac{\delta}{2} = 0.0000662 \sqrt[3]{P^2}$

Compression in hundredths of a millimeter

	P in kg. =	100	200	300	400	500	600	700	800
δ Total	Hertz	2.85	4.53	5.93	7.19	8.34	9.42	10.44	11.41
	observed	2.87	4.55	5.95	7.29		9.67		11.71
	averaged	2.85	4.54	5.98	7.28	8.48	9.60	10.65	11.68
δ_b Set	observed		0.07	0.17	0.24		0.48		0.67
	averaged			0.12	0.19	0.29	0.39	0.50	0.62

31 For each ball size the table gives the compression in hundredths of a millimeter under various loads.

The expressions for

$$\frac{\partial}{2}$$

at the head of each table are derived from Equation 1 with

$$\alpha = \frac{1}{2{,}120{,}000}$$

It forms the basis of the first line of compressions, which therefore are applicable only under the conditions of this equation. Since the limit of proportionality is exceeded with even the lowest loads cited, a deviation of these calculated values from the observed ones is to be expected, increasing with the loads.

32 Below these are given in the tables the observed and the average total compressions as well as the corresponding permanent sets.

33 The elastic modulus was determined by compressing cylinders of 16 mm. in diam. and 48 mm. in length. The measuring length was 32 mm.

34 As the available data concerning the influence of the hardening process on the material under test, or of the hardness on the elastic modulus, were incomplete and insufficient, the tests were extended to steel cylinders hardened in oil, hardened in water, and unhardened. As the behavior beyond the elastic limit also merits consideration that also was observed within the limitations of the mirror apparatus. The elastic recovery, which was the more noticeable the farther one was from the limit of proportionality, is included, notwithstanding the extraordinary labor resulting from its consideration.

35 The observed moduli of elasticity were found to be

for the unhardened cylinder $\alpha = \frac{1}{2{,}127{,}000}$

for the oil hardened cylinder $\alpha = \frac{1}{2{,}128{,}000}$

for the water hardened cylinder $\alpha = \frac{1}{2{,}102{,}000}$

36 The difference in round figures between the lowest and highest values is 5/4 per cent. Since, with the short length measured, errors of observation of this amount are not impossible, and since the elastic modulus for the oil hardened cylinder was found to be almost identical with that for the unhardened one, the average of all these observations

was taken as the probable value for the water hardened cylinder as well. This is, in round figures,

$$\frac{1}{2{,}120{,}000}$$

38 Beyond the limit of proportionality the various steel cylinders act very differently. See Fig. 5. While with the unhardened cylinder the permanent set rapidly increases, and while a limit of flow even is indicated, and with the oil hardened cylinder the compression curves after a sharp bend trend steeply upward, with the water hardened cylinder the rise is slow.

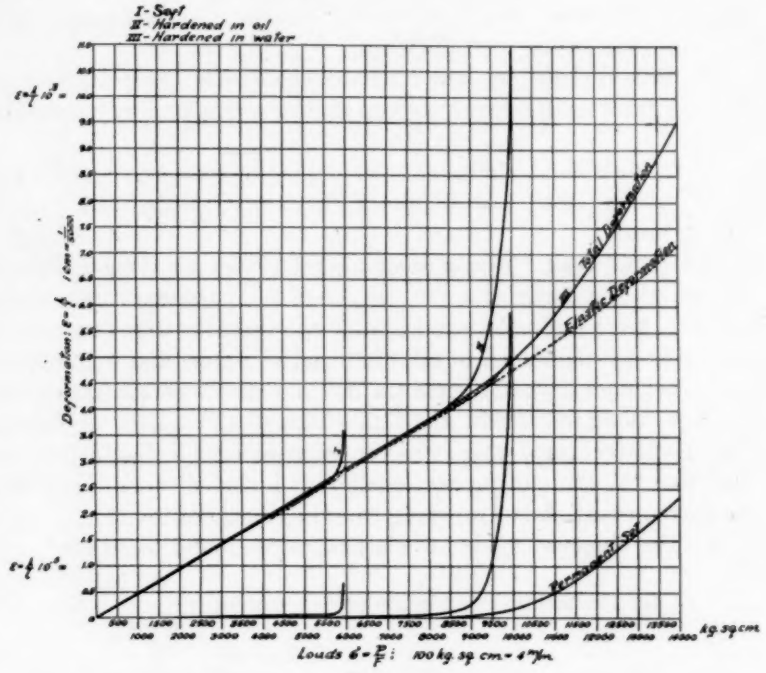

FIG. 5 BALL STEEL SUBMITTED BY THE DEUTSCHE WASSEN AND MUNITIONS FABRIKEN FOERLIN

COMPRESSION TESTS WITH CYLINDERS OF 16 MM. DIAM. 48 MM. LENGTH. MEASURED DISTANCE, 32 MM.

39 Since the compressions for two test pieces were measured together the value ∂ was inserted in the table. The compression of the individual test piece was therefore only one-fourth of the tabular value.

40 The difference between the total and the permanent compression gives the elastic compression.

41 The total compressions are greater beyond the elastic limit, but the elastic compressions are smaller than the values calculated

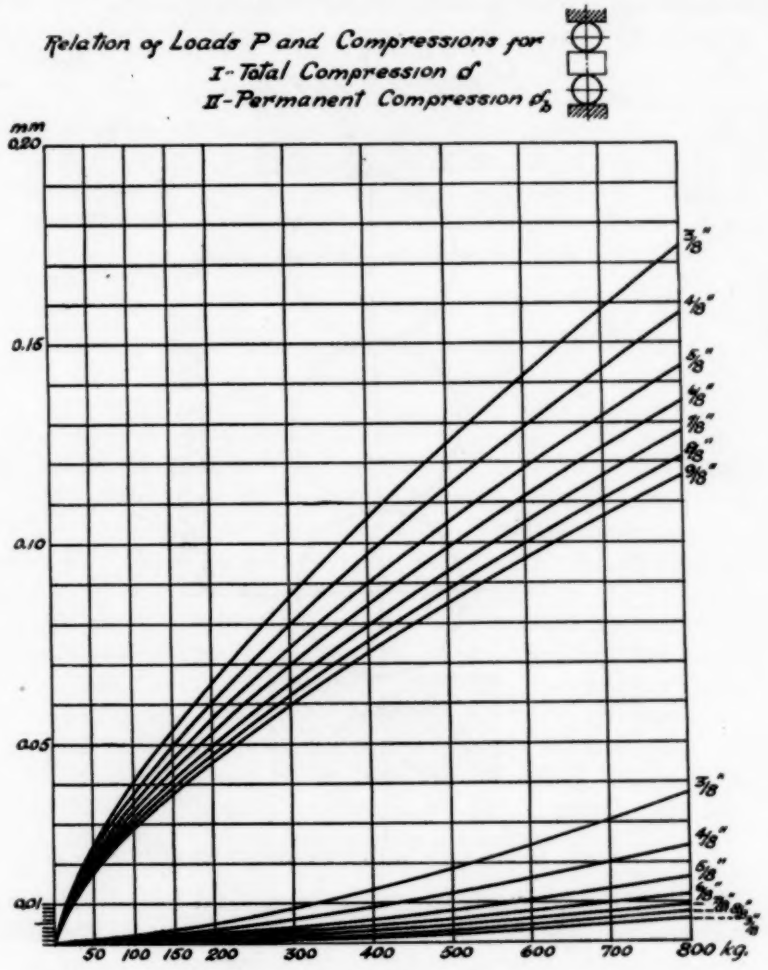

FIG. 6

from Equation 1. It is, however, readily seen, that even after the proportional limit is considerably exceeded, the differences are not material. This follows clearly from Fig. 14.

42 The average compressions are those derived by plotting as coördinates those values of d and δ, d and δ_b, as well as P and δ and

$P\,\partial_b$, respectively, that belong together, as is shown graphically by Fig. 6 to 8 and 10 to 12.

43 This averaging may be more completely carried through mathematically, but the greater complication and lesser oversight of this method is not sufficiently compensated for.

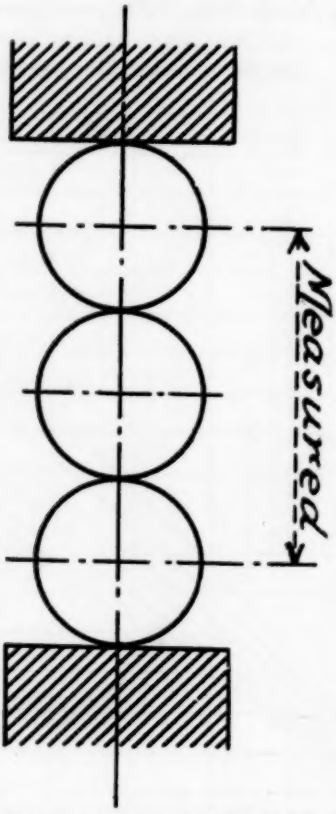

FIG. 6a BALL ON BALL TEST ARRANGEMENT

44 In the experiments with these superposed balls the average compressions really vary but slightly from the observed. The differences are particularly small with the total compressions, though rather greater with the permanent sets. Where the observed values are generally greater than the averaged ones, it is fair to assume that the balls are somewhat softer than the average and that they are rather harder when the observed values remain under the average ones. Errors arise chiefly from the balls not only approaching, but also rolling off of one another. This occurs when the outer balls do

not seat themselves fairly in their seats in the pistons, possibly because the centers of the three balls do not lie in the same straight line, so that the load does not act through the centers of the circular contact surfaces. It is not always easy to avoid these sources of error; the difficulties increase with the size of the balls. Disturbances may also be due to the pressure piston turning slightly as it is loaded or unloaded.

45 The difference between the observed and the averaged compressions are greater for ball and disc, this applying more particularly to the permanent deformations. The difficulties of the test were greatly increased by differences in the hardness of the discs and because the suitability of the discs could be determined only in the course of the test. Most of the discs were too soft, while a few were too hard.

THE LOAD AT THE ELASTIC LIMIT AND ITS RELATION TO THE BALL DIAMETER

46 In Fig. 6 and 10 the curves relating to the permanent set touch the axis of the abscissae near the origin. In reality neither these points of contact, nor yet the trend of the curves in their neighborhood, can be determined with certainty. Therefore the loads at the elastic limit cannot be deduced from these tests; nevertheless their dependence upon the ball diameters may be determined by a course of reasoning as follows: If surface stresses or other not yet known causes produce changes in the elastic limit such that the compressions at the elastic limit are dependent upon the curvature of the test piece—as Auerbach found for the brittle test pieces he examined—then these subsidiary phenomena cannot cease suddenly when the elastic limit is reached. Even with the cylindrical test piece the elastic limit is not a sharply defined characteristic point in the compression, still less is it so for two balls in contact.

47 Its advent does not make itself visibly manifest, since at first only a single element of the test piece is involved; only by raising the load is success had in stressing other elements to the elastic limit accompanied by a simultaneous increase of the pressure surface so that new surface elements are placed under elastic strain. Subsidiary influences will, therefore, in so far as they exist at all, certainly extend beyond the elastic limit. Auerbach reports also on experiments with plastic bodies in which the greatest attainable pressure also shows its dependence upon the curvature, generally accompanied by considerable permanent compression. For these greatest pressures Auerbach

Relation of Ball Diameter d and Total Compression δ for

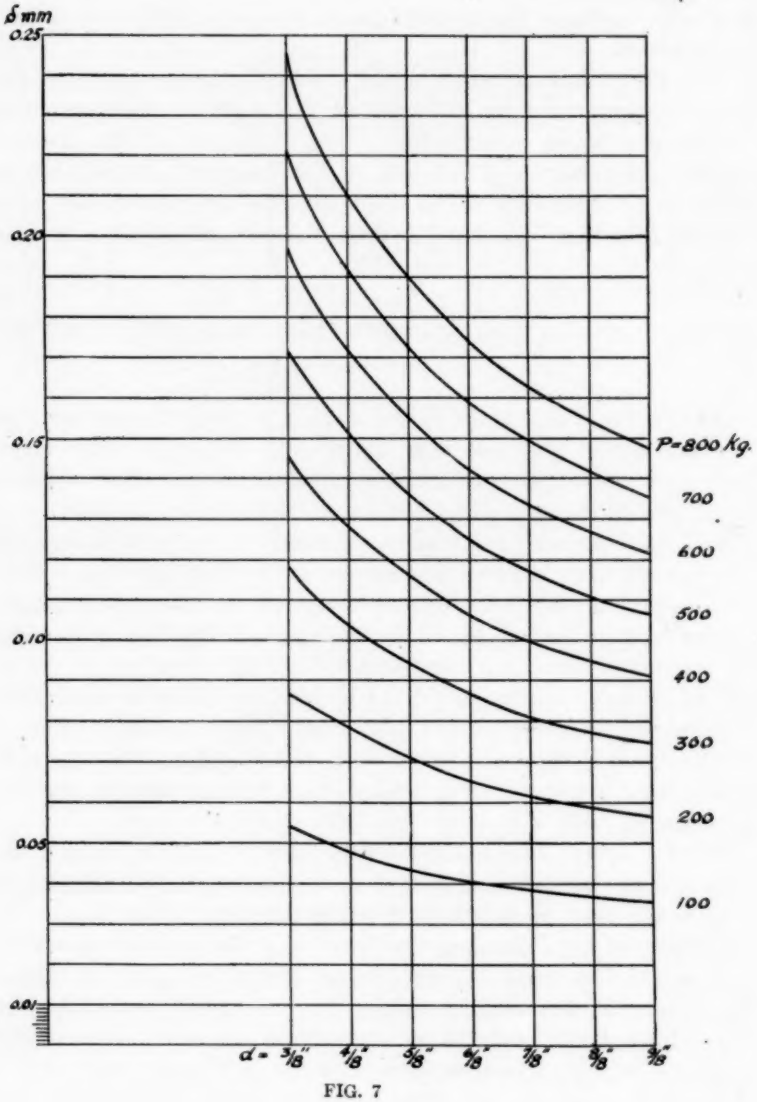

FIG. 7

found the same dependence upon the curvature of the object that he gives for the elastic limit of brittle bodies.

48 The test method employed and about to be described is based on these general considerations and experiences.

The elastic limit is defined by the permanent deformation amounting to a small part Δ, of the total deformation, such part differing but slightly from zero; If δ'_b and δ' are the deformations at the elastic limit, then

$$\frac{\delta'_b}{\delta} = \Delta$$

or, inserting the ball diameter d

$$\frac{\delta'_b}{d} : \frac{\delta'}{d} = \Delta$$

49 This expression we apply to small but sufficiently accurately measurable permanent deformations δ_b which belong to the total deformations δ while examining into the conditions under which $\frac{\delta_b}{d}$ as well as $\frac{\delta}{d}$ are constant. We shall assume that for $\frac{\delta_b}{d}$ = constant there exists the relation $P = k\ d^2$ k being the constant. Logically the same loads apply to δ and δ_b. The total deformations δ must therefore also be caused by loads $P = k\ d^2$. This condition, by Equation 1, results in $\frac{\delta}{d}$ = constant, which would be exactly true only at the limit of proportionality. For

$$P = k\ d^2$$

therefore also

$$\frac{\delta_b}{\delta} = \text{constant}.$$

50 But we know that in the absence of surface stresses and other subsidiary influences it must be that

$$P = k'\ d^2$$

at the elastic limit. Since the expression

$$P = k\ d^2$$

for which there would exist a deformation relation similar to that for the elastic limit, differs only in the constant factor, it may be deduced that, should our assumption hold true, surface strains do not exist with the introduction of the load and therefore do not exist at the elastic limit. We should then be justified in assuming as a fact that at the elastic limit $P = k'\ d^2$ and that the deformations for various ball diameters are the same.

51 The series of curves of Fig. 8 and 12 are suitable for this investigation. We shall first extend them to the contact of balls of the same size, as in Fig. 8, and select

$$\frac{\delta_b}{d} = 0.00025$$

so that the permanent compression of one ball is

$$\frac{\delta_b}{4} = 0.0000625\ d$$

52 In order to get the loads which for various ball diameters cause the permanent sets $\delta_b = 0.00025\ d$ we draw a diagonal $\frac{\delta_b}{d} = 0.00025$

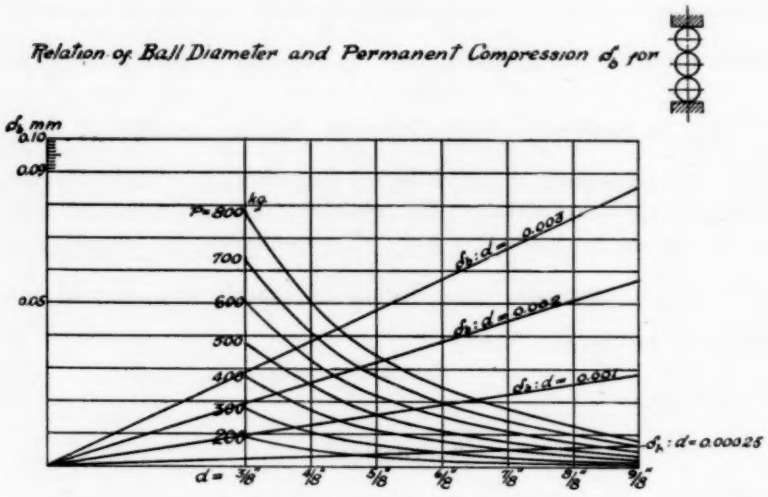

FIG. 8

through the curves of Fig. 8. The abscissa of each intersection gives us a diameter. The corresponding load is noted at the curve intersected. If now the squares of these diameters and the curves corresponding to them are plotted as coördinates and the points connected, a fairly straight line passing through the origin is given, as in Fig. 9. For since

$$\frac{\delta_b}{d} = 0.00025$$

it is true that

$$P = k\ d^2$$

53 Citing the numerical value found we get from Fig. 8

for P in kg. =	200	300	400	500	600	700
d in inches =	0.600	0.740	0.869	0.966	1.051	1.125
therefore $\frac{P}{d^2}$ =	556	547	530	536	545	553

54 Fig. 9 also gives the results of the investigation for some larger values of $\frac{\delta_b}{d}$. We see that the smaller $\frac{\delta_b}{d}$, the less the curves deviate from diagonals starting from the origin, that is to say, the nearer we get to the elastic limit.

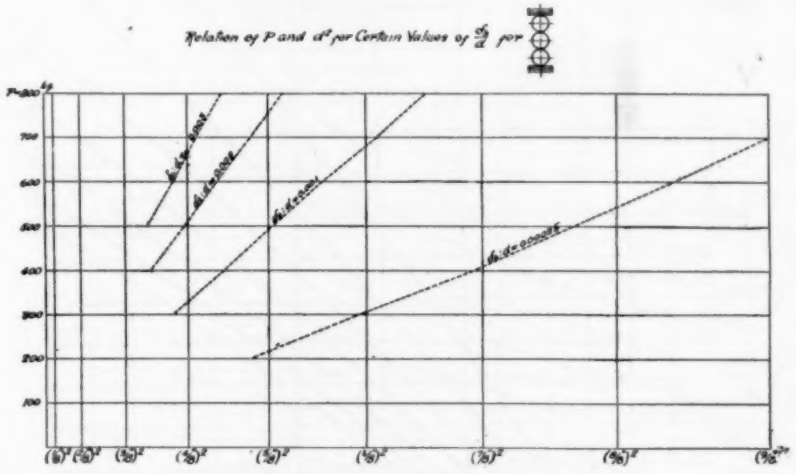

FIG. 9

55 The investigation of ball and disc gives the same result as is shown in Fig. 13. We have, for instance,

$$\frac{\delta_b}{d} = 0.000125$$

for which the permanent compression of one test object is 0.000031 d, and the corresponding values are

P in kg. =	200	300	400	500	600
and d in inches =	0.644	0.787	0.912	1.019	1.112
so that $\frac{P}{d^2}$ =	482	485	481	482	485

56 It is therefore proved that for balls of the hardened steels employed in these investigations, *at the elastic limit, the loads are propor-*

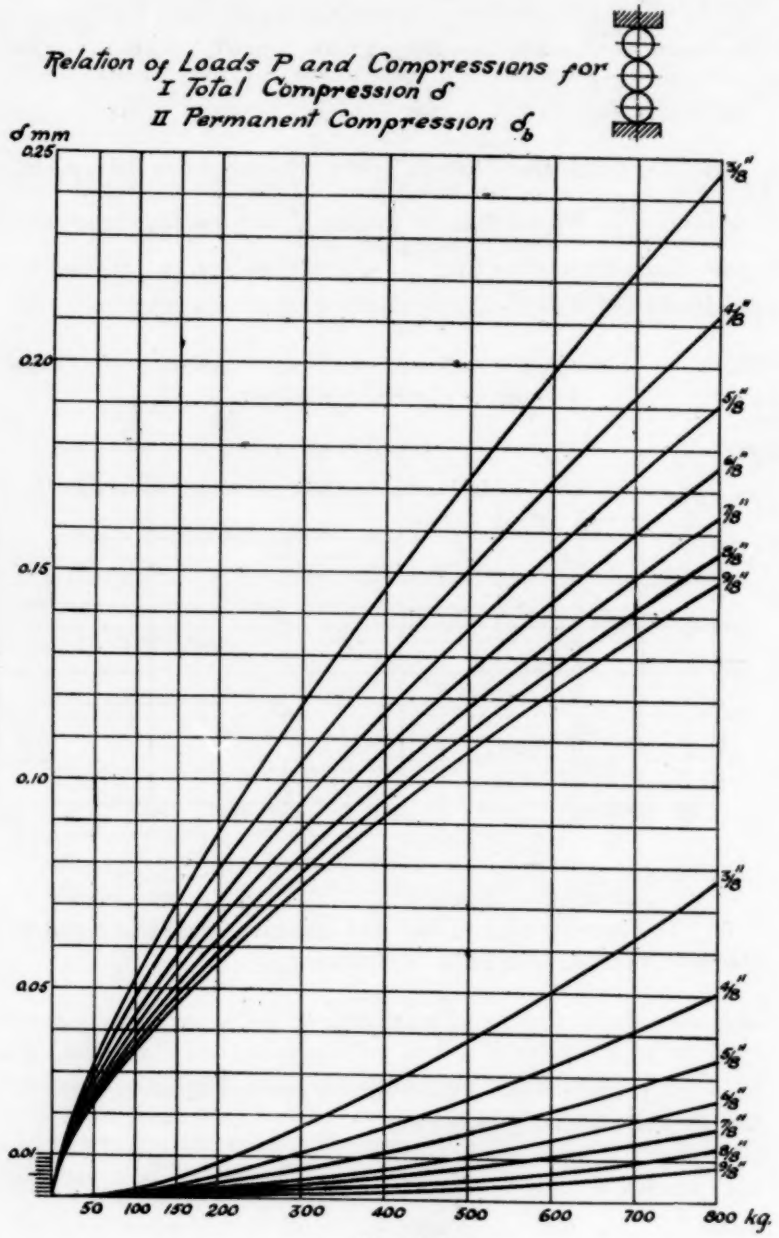
Relation of Loads P and Compressions for
I Total Compression δ
II Permanent Compression δb
δ mm
0.25
0.20
0.15
0.10
0.05
0.01
3/8"
4/8"
5/8"
6/8"
7/8"
8/8"
9/8"
50 100 150 200 300 400 500 600 700 800 kg.

FIG. 10]]]

tional to the squares of the diameters and that therefore the deformations are equal for all ball diameters. (Translator's Note: Since, see Table, compression $\frac{P}{d^2}$ is constant.)

THE EQUATION FOR THE PERMISSIBLE LOAD

57 From what has been said important conclusions may be drawn concerning the permissible load. Although other points of view

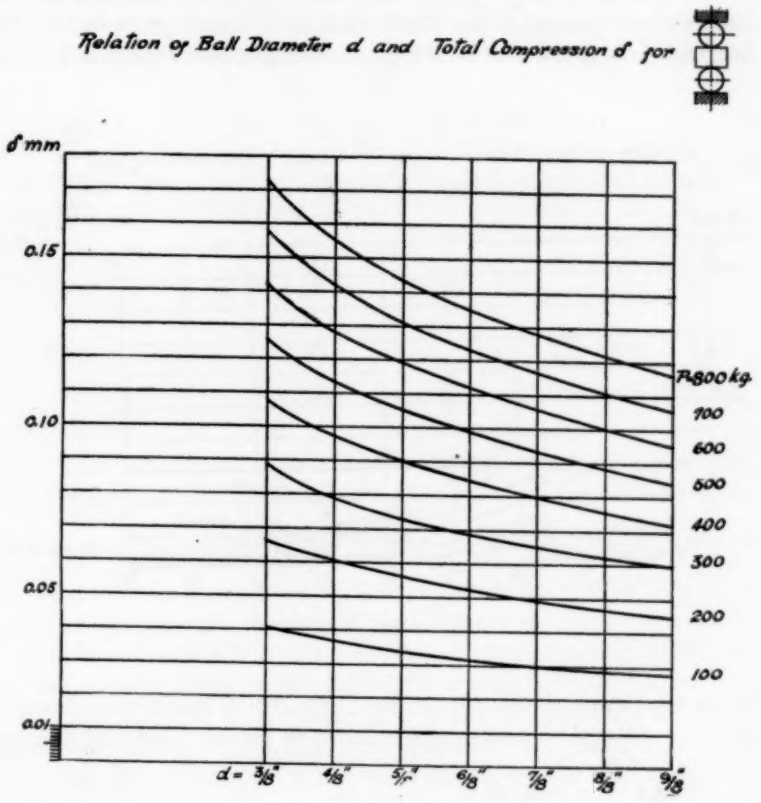

FIG. 11

which remain to be considered may be of influence, there are to be taken into account chiefly the greatest stress on the bodies, the pressure at the compression surfaces and the stress ratio $\delta_b : d$. We have been informed concerning the dependence of these values upon the load at the elastic limit as well as beyond that. Since these values, sometimes one sometimes another of which may determine the

permissible load, are equal for various ball diameters so long as a selection is made which gives $\frac{P}{d^2}$ = constant, for all these cases

$$P = k\,d^2 \qquad [4]$$

may be used as a basis for calculations and P be taken as the permissible load; k is then the permissible load for a unit diameter or the permissible specific load.

58 It is desirable to prove this relation, which has been derived from the occurrences under static load, by actual experience with ball bearings. In any event such experiments had to be made in order to

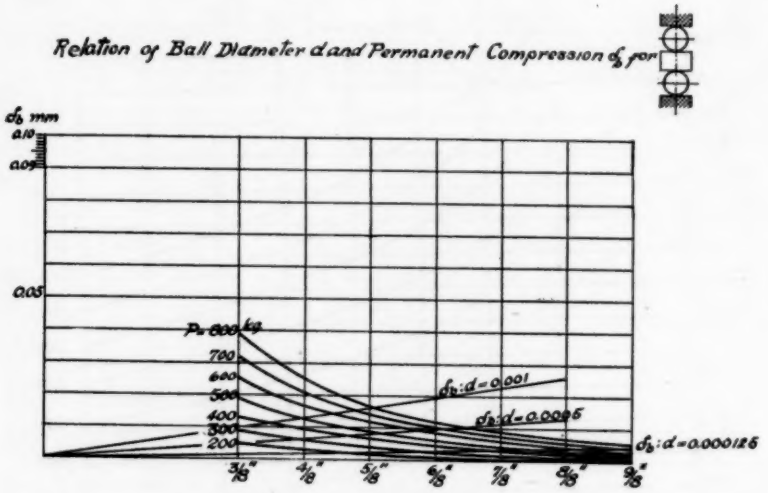

FIG. 12

get data for k and the friction values. Chapter 6 reports such investigations. Attention is here merely drawn to the fact that they confirm the relation $\frac{P}{d^2}$ = constant.

59 From the results of the compression tests with balls and disc deductions may be drawn giving the amount of the permanent compression δ_b for various values of $\frac{P}{d^2}$. Before taking up the investigation of ball bearings, it appeared advisable to represent this relation graphically, since that might give data for the permissible specific loads k.

60 After the curve series of Fig. 12 had aided in deciding that there corresponds to a definite, but small value of $\frac{\delta_b}{d}$ also a definite value of $\frac{P}{d^2}$, it became easy to determine, with the aid of the same series of curves, that particular value $\frac{\delta_b}{d}$ belonging to any value of $\frac{P}{d^2}$.

61 In the following table k is the permissible load in kg. for a diameter of $\frac{1}{8}$ inch English. In the equation $P = k\,d^2$ the unit for d is therefore $\frac{1}{8}$ inch. The selection of this value as unity is justified because balls are manufactured to the English system of measurement while the formula may be readily transformed into cm. since, for

$$d \text{ in cm. } k = \left(\frac{1}{0.3175}\right)^2 = 9.92$$

or, in round figures, k is ten times as great as for eighths of an inch.

k in kg. per $\frac{1}{8}$ inch	=	4	5	7.5	10	15	20
$\frac{\delta_b}{d}$ .1000	=	0.047	0.067	0.125	0.204	0.374	0.555
$\frac{\delta}{d}$ .1000	=	2.24	2.61	3.41	4.14	5.50	6.65
$\frac{\delta_b}{\delta}$	=	0.021	0.026	0.037	0.049	0.068	0.083

62 This influence of k on the deformation is more clearly grasped from the graphic representation of Fig. 15. Note particularly the curve $k, \frac{\delta_b}{d}$. With the aid of curves $k, \frac{\delta}{d}$ and $k, \frac{\delta_b}{\delta}$ this curve may with fair certainty, be determined almost to the origin. Since this curve comes in contact with the axis of the abscissae the permanent sets at first increase but slowly. With $k = 2$, δ_b is approximately $0.000015\,d$, and for each pressure point one-fourth of this. For instance, for $d = 20$ mm. 0.00008 mm. With $k = 4$ the compression is already three times and with $k = 6$, it is six times as large; with $k = 10$ the curve has almost reached its greatest inclination to the axis of the abscissae. Though this trend of the curve does not admit of definite conclusions, it may yet lead others, as it has me, to suppose that for a ball or disc or similar conditions k would lie between 2 and 6, and that 10 might be too high. One would have to conclude, not that the resultant change from sphericity would increase the resistance to motion, but rather that this extraordinary stressing of the material would sooner or later damage the parts and more particularly the races.

63 Should the experiment with ball bearings actually lead to k smaller than 6, that would indicate the advisability, at least for heavy loads, of so shaping the races that they present a larger supporting surface to the balls. For this reason $\frac{5}{8}$ inch balls were also pressed against grooved cylinders, as shown in 3 of Fig. 14, whose groove radius of curvature was $\frac{3}{4}$ of the ball diameter. For equal loads and compressions within the limit of proportionality we calcuate, according to Hertz, the load for disc and ball is to that for cylinder and ball as 1: 3.56. The ratio of the deformations approximates as 1: 5/3.

64 Beyond the limit of proportionality and within the region of permissible loads the difference in favor of the grooved cylinder and ball is rather smaller. A load 3.56 times as great would for grooved cylinder and ball give rather greater deformation and, more particularly, greater sets, than for balls on flat discs, as will be seen by comparing Fig. 14.

65 Nevertheless it is to be expected that the permissible load for hollow cylinder and ball is materially greater than for ball and plane disc. Conclusive data are also to be expected only from experiments with ball bearings, since balls and races are subject to further influences that come in with relative motion.

TABLE 3

COMPRESSION IN HUNDREDTHS OF A MILLIMETER FOR A GROOVED CYLINDER BETWEEN TWO BALLS OF $\frac{5}{8}$ INCH DIAMETER

According to Hertz $\frac{\partial}{2} = 0.000057 \sqrt[3]{P^2}$

P in kg. =		50	100	200	300	400	500	600	700
∂	Hertz.....	1.55	2 46	3.90	5.11	6.19	7.18	8.11	9.82
∂	observed	1.59	2.56	4.11	5.39	6.51		8.48	10.21
∂_b	observed	0.01	0.06	0.13	0.18	0.25		0.40	0.57

THE FRICTIONAL WORK OF BALL BEARINGS

THE MOVEMENTS AND THE EQUATION FOR THE FRICTIONAL WORK

66 Assume that a ball move between the surfaces of rotation of two ball races, of which each may present to the ball two supporting surfaces A_1 A_2 and B_1 B_2, but otherwise have any desired shape. See Fig. 16. The race A_1 A_2 is to revolve around its axis with reference to race B_1 B_2 at an angular velocity ω. The center A of distance A_1, A_2 is distant from the axis rotation by R. R is the mean radius of the rotation surface A_1 A_2. The velocity of point A is therefore $R\omega$.

67 The speeds which determine the frictional work are here to be chiefly considered. There must be taken into account the movements of the balls with relation to the race surfaces $B_1\ B_2$ and $A_1\ A_2$. The one has rotation around the instantaneous axis $B_1\ B_2$ the other, rotation around $A_1\ A_2$ as an instantaneous axis. Let the angular velocities of these rotations be ω_b and ω_a.

68 If there is to be no sliding at the centers of the supporting surfaces, then the three axes of rotation $W\ W$, $A_2\ A_1$, and $B_2\ B_1$ must either meet in one point or be parallel.

69 The ball center is distant from $B_1\ B_2$ by b and point A by e.

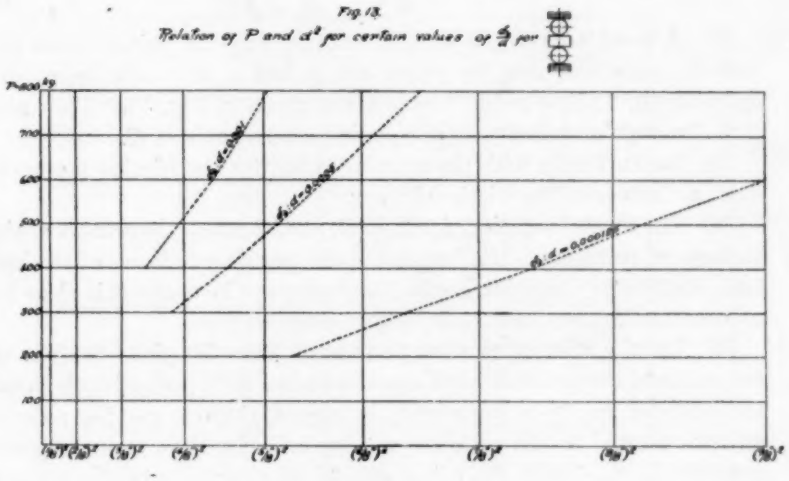

FIG. 313

Let ω_o be the angular velocity with which the ball center rotates in a circle of radius R_o around the axis $W\ W$ then

$$\omega_b = \frac{R}{e}\ \omega$$

and also

$$\omega_b = \frac{R_o}{b}\ \omega_o \qquad [5]$$

so that

$$\omega_o = \frac{R}{R_o}\ \frac{b}{e}\ \omega$$

70 The expression for ω_a is readily found if race $A_1\ A_2$ be consid-

ered stationary with the ball center rotating around axis $W\ W$ with the angular velocity $\omega_o - \omega$. This is true since we have

$$\omega_a = \frac{R_o}{a}(\omega_o - \omega)$$

and also

$$\omega_a = -\frac{R_o}{a}(\omega - \omega_o)$$

71 The minus sign indicates that this rotation and the rotation of race $A_1\ A_2$ are opposed.

Replacing w_o its equation as found gives

$$\omega_a = -\frac{R_o}{a}\left(1 - \frac{R}{R_o}\frac{b}{e}\right)\omega \qquad [6]$$

72 A good conception of the velocity ratio is gained from the velocity parallelograms, by whose aid ω_a and ω_b may also be rapidly determined. These parallelograms are given in Fig. 16. They also give the angular velocity ω_c of rotation around axis $M\ C$.

73 Concurrently with the angular velocities the friction moments exist as factors of the frictional work.

74 The axes of rotation A_1A_2, B_1B_2 pass through the centers of the surfaces of rotation. All elements in the pressure surfaces of the ball have elementary rotation around these axes. To make this clear let us consider the occurrences at one pressure surface.

75 Let the axes of rotation form angle with the plane tangent to the center of the pressure surface as shown in Fig. 17; conceive the rotation divided into two elementary rotations, the one moving around an axis normal to the pressure surface and therefore at an angular velocity $\omega_b \sin \phi$, and the other around an axis lying in the contact surface and therefore at an angular velocity $\omega_b \cos \phi$.

a It is a fundamental condition for rotation around the normal axis with velocity $\omega_b \sin \phi$ that the elements in the pressure surface of ball and race slide on one another. The resultant friction may be considered as step friction. For its calculation the dimensions of the pressure area, which by the way is an ellipse, would have to be determined by Hertz's investigations and it be considered that, according to Hertz, the deformations increase from the edge toward the center, as do the ordinates of an ellipsoid erected over the pressure area ellipse.

b Rotation around the axis in the contact plane, whose angular velocity is $\omega_b \cos \phi$ is opposed by a resistance which may be called the rolling friction of the ball, but which also is not free of sliding friction.

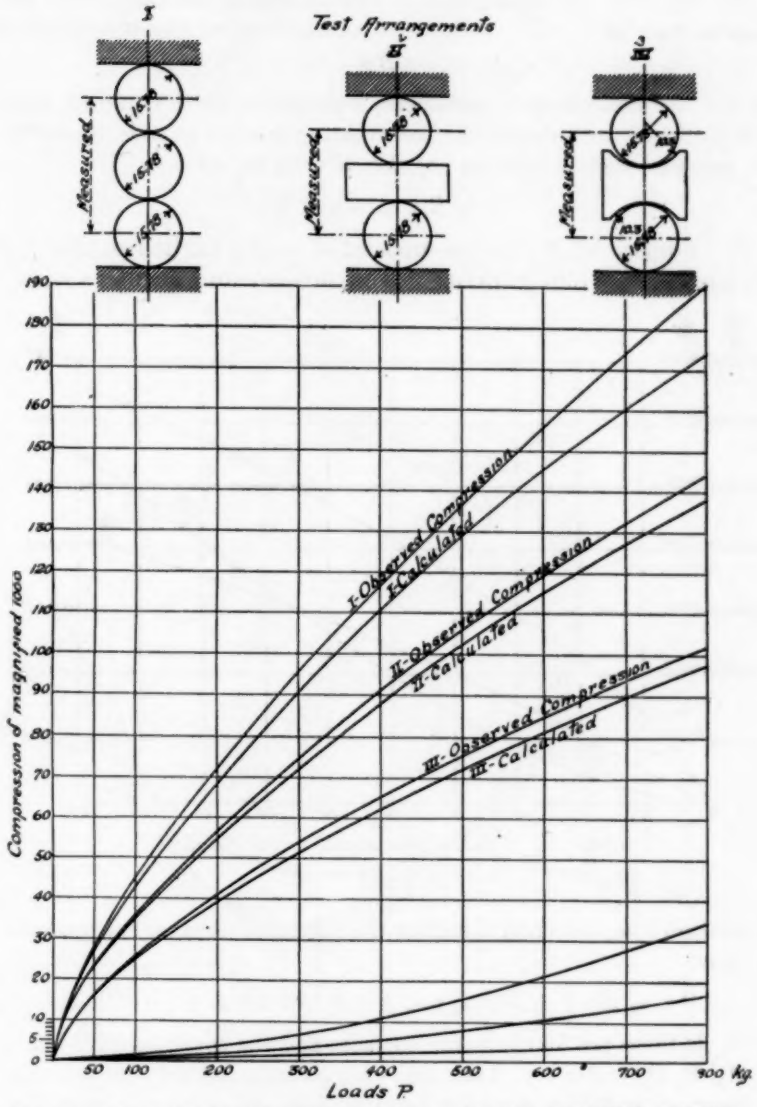

FIG. 14 RELATION OF COMPRESSION AND LOAD FOR THE THREE TESTS

I 3 balls $\frac{15}{16}$" diam. in line. Compression according to Hertz $\frac{\delta}{2} = 0.0001014 \sqrt[3]{P^2}$

II 2 balls $\frac{15}{16}$" diam. and flat disc. Compression according to Hertz $\frac{\delta}{2} = 0.000057 \sqrt[3]{P^2}$

III 2 balls $\frac{15}{16}$" diam. and grooved cylinder. Compression according to Hertz $\frac{\delta}{2} = 0.000057 \sqrt[3]{P^2}$

Modulus of elasticity $= \frac{1}{2{,}120{,}000}$

76 Let B be the thrust load and let us express the moment of the step friction as

$$\mu B x$$

with μ the mean friction coefficient, x the mean friction radius, then the frictional work due to the ball rotating around an axis normal to the pressure surface with an angular velocity $\omega_b \sin \phi$ is

$$\mu B x \omega_b \sin \phi$$

77 Further let $B f$ be the moment of rolling friction so that f is the coefficient of rolling friction. The corresponding angular velocity

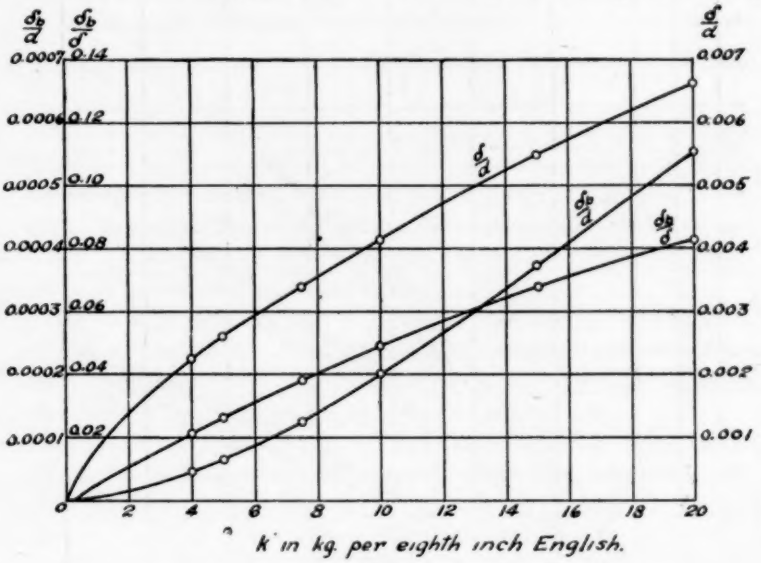

FIG. 15

of rotation is $\omega_b \cos \phi$ and therefore the frictional work for one pressure surface

$$\mu B x \omega_b \sin \phi + B f \omega_b \cos. \phi = B (\mu x \sin \phi + f \cos \phi) \omega_b$$

78 If there are four pressure surfaces and the corresponding loads A_1 A_2, B_1 B_2 and α and β the acute angles included between the axis of rotation and the pressure surface, then the frictional work for the four pressure surfaces is

$$A_1 (\mu_1 x_1 \sin \alpha + f_1 \cos \alpha) \omega_a$$
$$A_1 (\mu_2 x_2 \sin \alpha + f_2 \cos \alpha) \omega_a$$
$$B_1 (\mu_1' x'_1 \sin \beta + f'_1 \cos \beta) \omega_b$$
$$B_2 (\mu_2' x'_2 \sin \beta + f'_2 \cos \beta) \omega_b$$

Their sum gives the total frictional work A_r.

As a rule it would be permissible to say:

$$\mu_1 = \mu_2 = \mu\,;\ \mu'_1 = \mu'_2 = \mu'$$
$$f_1 = f_2 = f\,;\ f'_1 = f'_2 = f'$$

so that

$$A_r = [(A_1 x_1 + A_2 x_2)\ \mu\ sin\ \alpha + (A_1 + A_2)\ f\ cos\ \alpha]\ \omega_a + [(B_1 x'_1 + B_2 x'_2)\ \mu'\ sin\ \beta + (B_1 + B_2)\ f'\ cos\ \beta]\ \omega_b \quad [7]$$

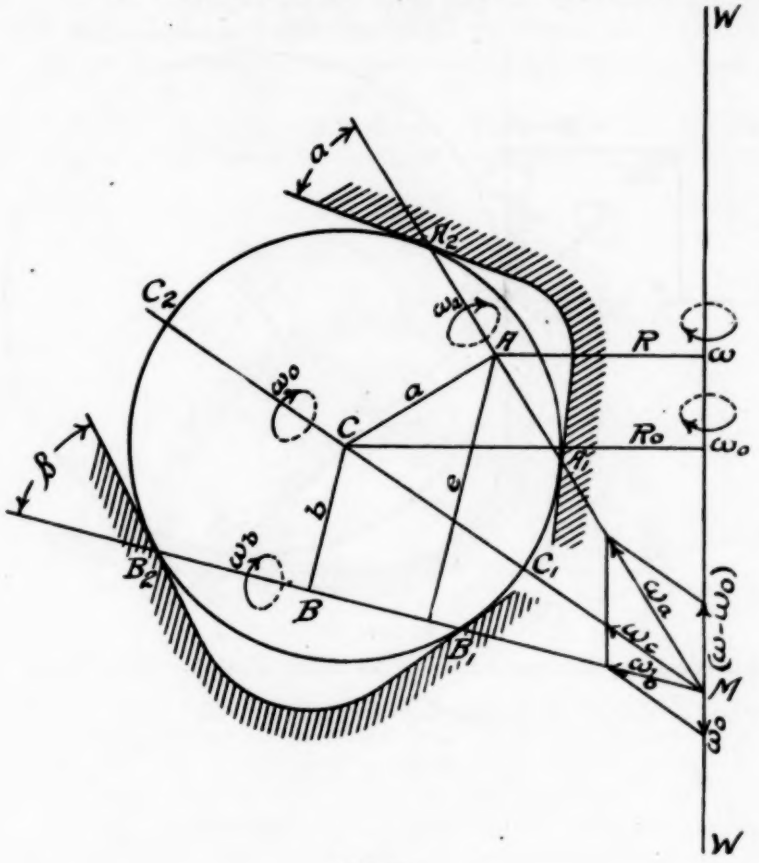

FIG. 16

79 The long continued experiments with ball bearings which have been carried out in the Central Laboratory give information for the value of $\mu\ x$ and f. For the determination of the rolling friction f those bearings are particularly suitable for which α and $\beta = 0$, so that the step friction disappears.

80 In this case also

$$A_1 + A_2 = B_1 + B_2 = S$$

and therefore

$$A_r = Sf\omega_a + Sf'\omega_b \qquad [8]$$

f and f' will not be equal, since the ball makes contact with one race at the inner and with the other at the outer running surface. Nevertheless it is, for practical reasons, advisable to use

$$A_r = Sf\,(\omega_a + \omega_b) \qquad [8a]$$

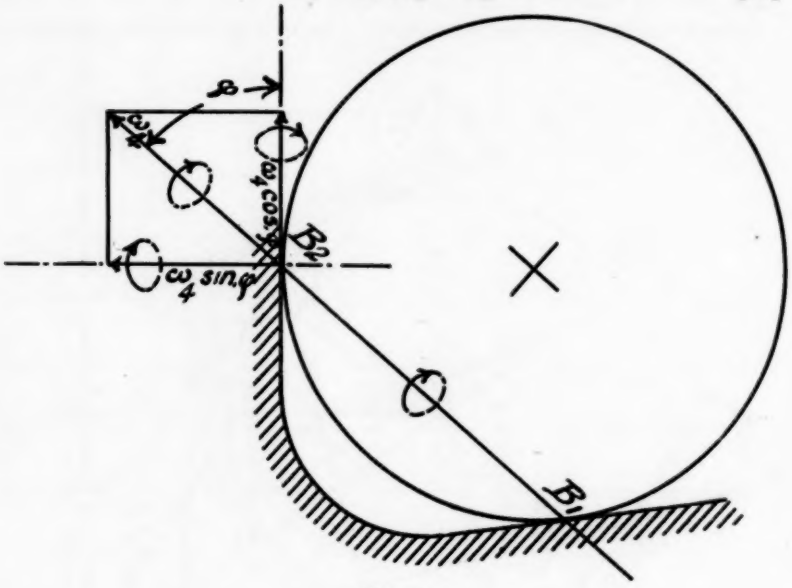

FIG. 17

and to consider f the mean coefficient of rolling friction. Since further $a = b = \frac{e}{2}$ and $e = d$, it follows

first that

$$\omega_a = \frac{2R_o}{d}(\omega - \omega_o)$$

$$\omega_b = \frac{2R_o}{d}\omega_o$$

and therefore that

$$A_r = Sf\frac{2R_o}{d}\omega = Sf\frac{D_o}{d}\omega \qquad [9]$$

81 It is to be especially noted that the frictional work increases with the ratio $\frac{D_o}{d}$. To have it as low as possible the balls must rotate around the smallest circle.

82 If there is room for z balls in the race and if z is sufficiently large so that approximately

$$\pi D_o = z d$$

and therefore

$$\frac{D_o}{d} = \frac{z}{\pi}$$

then it may be said, for the case of the balls having only rolling motion that *the frictional work is smaller the fewer balls there are in a race.*

83 It may therefore prove advisable to start with the number of balls belonging to a pair of races.

84 The above values apply to one ball only. The total friction of a bearing is the sum of the frictional work found for the individual

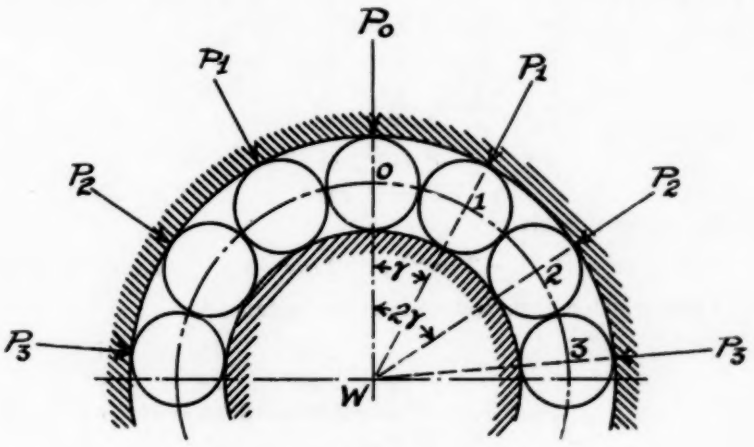

FIG. 18

balls. Since ω_a and ω_b and α and β have equal values for all balls, the rolling friction is calculated from the expression given for the individual ball, by inserting the sum of the loads of all balls for S. The rolling friction coefficient f is then to be taken as that for the bearing as a whole and not that of the individual ball. On the other hand, the calculation of the sliding friction is more complex, since the values of x are dependent upon the individual loads.

85 The first task therefore is the determination of the individual loads of a bearing as well as of the total loads on the balls of a bearing.

86 If P is that portion of a journal load carried by one ball row, then for the simple case of Fig. 18,

$$P = P_o + 2 P_1 \cos\gamma + 2 P_2 \cos 2\gamma + \ldots + 2 P_n \cos n\gamma$$

in which

$$n\,\gamma < 90^\circ$$

and as a rule

$$\gamma = \frac{360}{z}$$

therefore

$$n < \frac{z}{4}$$

87 Let δ_o be the approach of the two races in the direction of radius $W\,O$ under load P_o; the approaches $\delta_1\,\delta_2$, etc., correspond to P_1 P_2, etc.

88 If, before load is applied, there is no play between the balls and races and the races are not appreciably deflected under the loads $P_o\ P_1$, etc.

then $\delta_1 = \delta_o\ cos\ \gamma_1\ \delta_2 = \delta_o\ cos\ 2\ \gamma$, etc.

$$\frac{P_o^{\,2}}{\delta_o^{\,3}} = \frac{P_1^{\,2}}{\delta_1^{\,3}} = \frac{P_2^{\,2}}{\delta_2^{\,3}} = \frac{P_n^{\,2}}{\delta_n^{\,3}}$$

and therefore

$$P_1 = P_o\ cos^{3/2}\ \gamma$$
$$P_2 = P_o\ cos^{3/2}\ \gamma$$

Equating this gives

$$P = P_o\ (1 - 2\ cos^{3/2}\ \gamma - 2\ cos^{3/2} 2\ \gamma \ldots . 2\ cos^{3/2}\ n\ \gamma) \quad [10]$$

From which calculation we have for instance for

$z =$	10	15	20
$\gamma =$	36°	24°	18°
$\frac{P}{P_o} =$	2.28	3.44	4.58
$=$	z	z	z
	4.38	4.36	4.37

$$P_o + 2P_1 + \ldots . + 2\ P_n = 1.23\,P \quad 1.22\,P \quad 1.21\,P$$

89 The sum of the individual loads is almost invariable and the values also of $\frac{P}{P_o}$ are almost exactly equal to $\frac{z}{4.37}$.

Therefore for

$$z = 10 \text{ to } 20$$

the largest load per ball is

$$P = \frac{4.37\,P}{z}$$

90 Actually the assumptions that before loading the balls move without play in the races and that the races do not deflect under load,

are not responded to so that the highest load on one ball will be greater and the sum of all individual loads smaller than the calculated values.

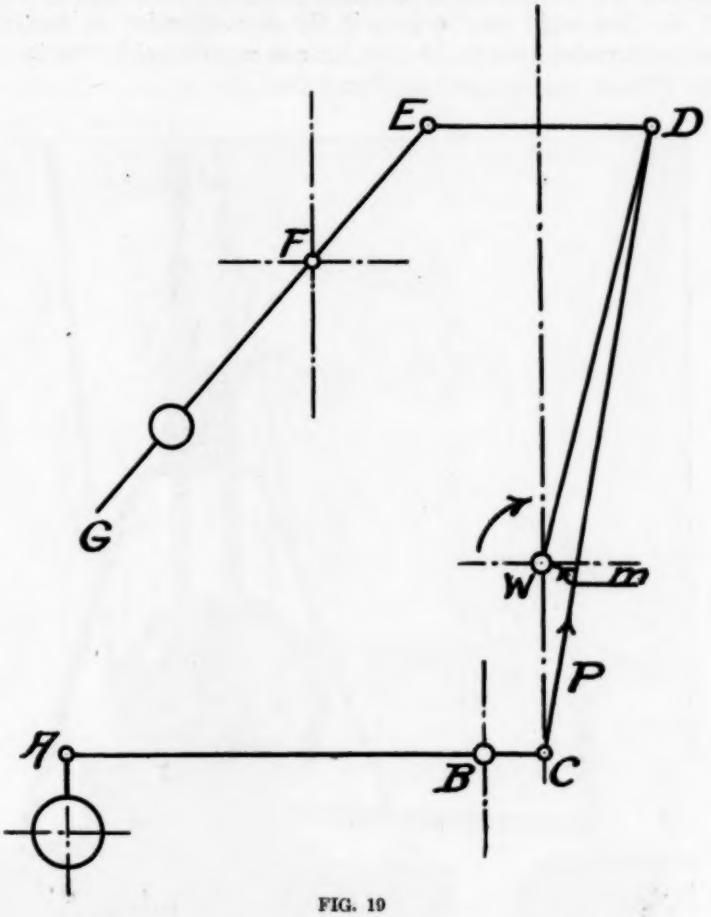

FIG. 19

If we take for

$$z = 10 \text{ to } 20$$

$$P_o = \frac{5\,P}{z} \qquad [11]$$

and

$$P_o + 2\,P_1 + \ldots . 2P_n = 1.2\,P \qquad [12]$$

then we get for

$z =$	10	15	20
$P =$	$\frac{P}{2}$	$\frac{P}{3}$	$\frac{P}{4}$

(P = bearing load)

Experiments With Ball Bearings

THE FRICTION SCALE OF THE CENTRAL LABORATORY

91 The scale was to permit the determination of the friction moment under loads up to 5000 kg. and any desirable rotative speed. Its scheme is illustrated by Fig. 19.

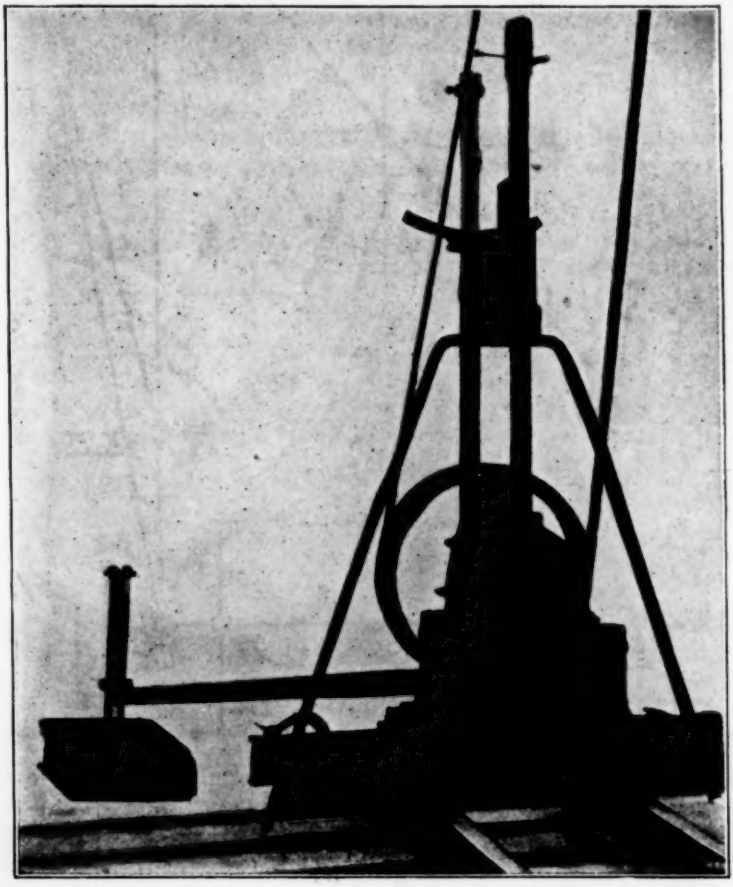

FIG. 20

92 The beam *A B C* of unequal levers carries the loading weight at the end *A* of its long lever arm. The strut *C D* is supported at the end of the short lever arm *E* and transmits the load to the bearing through the suspension rods *W D*. The bearing surrounds a shaft that is journaled on either side in blocks and that may be rotated in opposite direction by suitable means.

93 So long as force P at C acts in the direction of connecting line $C\,D$, then with the shaft rotating in the direction of the arrow, the rod will deviate sidewise in the indicated direction and the friction moment of the bearing be Pm being equal to the distance of force P from axis W. Considering the friction moment as the product of an ideal friction $\mu_i P$ and r its distance from the shaft axis, then, to get equality of moments,

$$\mu_i Pr = Pm$$

$$\mu_i r = m \qquad [13]$$

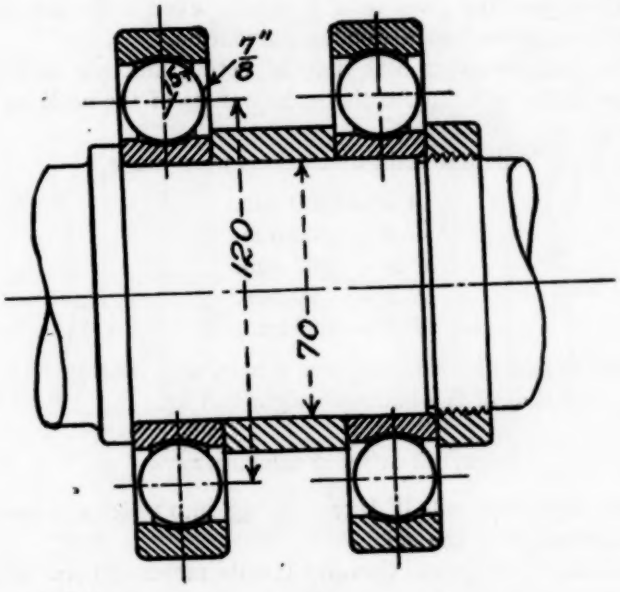

FIG. 21

Since r has a definite value for every bearing μ_i is proportional to m. The deviation of the rod is therefore proportional to the ideal friction coefficient of the bearing.

94 In order not to sensibly change the direction $C\,D$ of the force P by friction at the supports, the strut is carried on hardened steel knife edges.

95 It must be taken into consideration that the weights of the strut $C\,D$, suspension rods $W\,D$ and the bearing act as rotating forces. To equalize their moments a second swing $E\,F\,G$ of smaller dimensions is employed, whose upward arm is connected to $C\,D$ by a short link $E\,D$ and whose downward arm $F\,G$ carries the balance weight.

If $F E$ is made small with relation to $C D$, a small balance weight only is needed. Shaping $F G$ as a pointer playing over a curved scale will permit a more open scale reading of the friction coefficient and therefore greater accuracy than reading directly from the deviation of the main swing $C D$.

96 To adjust the strut $C D$ so that its axis is simultaneously vertical and in line with the shaft axis is rather difficult. The balance weight permits the elimination of this necessity, provided the shaft is first rotated in one and then in the opposite direction and the readings of the pointer taken in both directions.

97 This proceeding gives reliable results, even when the scale is temporarily supported on a wooden foundation.

98 The balance swing and the connecting link are carried on knife edges so as to influence the sensitiveness of the scale as little as possible.

As Fig. 20 is built the main dimensions were made

$$A B = 1000 \text{ mm.}$$
$$C B = 50 \text{ mm.}$$
$$C D = 1560 \text{ mm.}$$
$$E F = 90 \text{ mm.}$$
$$F G = 360 \text{ mm.}$$

The total weight of strut, supporting rods, and bearing box was 74.70 kg. and that of the balance weight 0.3 kg.

CARRYING OUT THE EXPERIMENTS

99 The suspension rods $W D$ carry a box into which the bearings may be inserted from the side.

100 An oil of moderate viscosity (Deutz motor oil) was used in such quantity that the bottom ball just dipped through it. Ball bearings may not be run without lubrication.

101 The oil temperature was determined by a thermometer inserted into the oil at one side of the bearing. This was sufficient since the temperature varied but slowly. So long as the balls do not lie in the oil, but are only moistened as may be required, the influence of the oil temperature on the bearing resistance is immaterial. It would probably be difficult to determine this influence, since the temperature will alter the shape of the bearings and races, which would also materially change the frictional conditions.

102 The ball bearing that was examined first made 65, 100, 130 190, 380, 780 and 1150 r. p. m. The lowest speed was taken first. The load was increased step by step from a small amount to the high-

est, and then again decreased in the same way. If, with similar loads, lower frictional values were observed with the decreasing load series, while the temperature did not differ materially it permitted the assumption that the bearing had not got down to good running conditions. The gradual reduction of the frictional values is very noticeable with bearings whose race surfaces were only roughly ground after hardening. *It is almost unnoticeable with races that have been so well finished that grinding scratches are not visible with the naked eye. This condition of the ball tracks is very important for the durability of races and balls.*

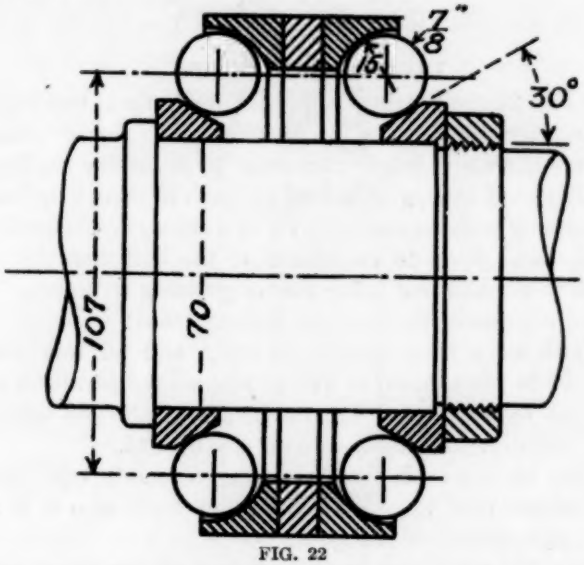

FIG. 22

103 The same proceeding was followed with the same loads at all other speeds. If no disturbance arose before its conclusion the bearing was then examined. If neither the races nor balls indicated damage the investigation was continued, beginning again with the lowest speeds, but taking higher limiting values for the loads. When finally the appearance of the impressions indicated that the permissible load had been materially passed, a final endurance run at 780 r. p. m. with the greatest test load was made. By giving due consideration to the various observations the specific load k could be readily deduced.

104 The experience gained was naturally utilized for the later experiments, so that results were reached with less load and speed steps.

105 The friction scale gives directly only the ideal bearing friction coefficient. This was referred to the shaft diameter, so that the results may be directly compared with the sliding friction of plain journals. We have therefore to consider the friction as equivalent to a resistance acting at the shaft circumference; the observation values are therefore the ratios of this resistance and of the bearing load. Since the radius of the shaft for all bearings tested was 3.5 cm., we find that with reference to the deviation m of the main swing of the friction scale, according to Equation 13 was

$$\mu_i = \frac{m}{3.5} \quad \text{with } m \text{ in cm.}$$

THE FRICTIONAL VALUES

106 In Fig. 21 the bearings were each made up of two ball races. This construction was found to be best for heavy loads. Four such bearings were therefore tested.[1] In order to determine the best steel different alloys and makes were used for each of these four bearings. The race running surfaces were grooves of a circular cross section with arcs having radii equal to two-thirds of the ball diameter. They were carefully finished and fairly free of grinding scratches.

107 The abundant observations indicate that:

a With loads from 1000 to 3000 kg. and all test velocities 65 to 780 r. p. m. as well as with oil temperatures of from 18 to 40 degrees C., the friction coefficient differs but slightly. Its mean value is $\mu_i = 0.0015$.

b This friction coefficient increases noticeably only for loads below 1000 kg. With these low loads also it is almost independent of the speed.

108 Since the coefficient is independent of the speed within a wide speed range, the results can be given by the few values of the following table:

TABLE 4

R. P. M. =	65	385	780
Bearing load 380 kg, corresponding to 1.4 d^2* μ_i =	0.0033	0.0035	0.0037
Bearing load 850 kg. corresponding to 3.1 d^2 μ_i =	0.0020	0.0021	0.0022
Bearing load 1100 kg. corresponding to 4.0 d^2 μ_i =	0.0017	0.0018	0.0019
Bearing load 1580 kg. corresponding to 5.8 d^2 μ_i =	0.0016	0.0016	0.0015
Bearing load 2050 kg. corresponding to 7.5 d^2 μ_i =	0.0015	0.0015	0.0015
Bearing load 3000 kg. corresponding to 11.0 d^2 μ_i =	0.0015	0.0013	0.0013
Bearing load 4900 kg. corresponding to 17.9 d^2 μ_i =			0.0011

*d = ball diameter in eighths of an English inch and 1.4 d^2 = largest load per ball.

[1]Translator's Note: The use of several rows of balls is admissible only under conditions that permit an equalization of the total load among the several rows. This condition is but rarely fulfilled in practice, so that one row to a bearing and that heavy enough, must be considered the standard arrangement.

109 The merely moderate variations of the observations have been previously averaged. It may be assumed that with less careful workmanship or a too great flooding of the bearing with a heavy lubricant the speed will be of greater influence on the bearing resistance.

110 For loads from the permissible to half that value, that is to say, from 3000 to 1500 kg. μ_i varies between 0.0013 and 0.0017.

The coefficient f of rolling friction is to be derived from

$$\mu_i \, Pr = Sf \frac{D_o}{d}$$

in which S is the sum of all the individual ball loads and is, as has

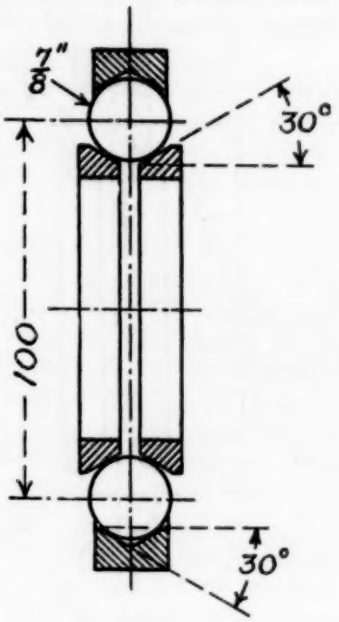

FIG. 23

been previously shown, $= 1.2 \, P$ with P representing the bearing load; it therefore holds true that

$$\mu_i \, r = 1.2 \, f \frac{D_o}{d}$$

and with

$$r = 3.5 \text{ and } \frac{D_o}{d} = 4.4$$

$$f = \frac{3.5}{1.2 \text{ x } 4.4} = \frac{2}{3} \mu_i$$

with μ_i =0.0013 to 0.0017 it follows that f = 0.0009 to 0.0011.

111 In Fig. 22 the journal was made up of two ball rows. It ran with 65, 130, 190, 385, 580, 780 r. p. m. and under loads from 380 to 3000 kg. The friction coefficients are almost 15 per cent greater than for the design of Fig. 21. As for the rest, the speed had similarly little influence as with Fig. 21.

112 The journal in Fig. 23, consisting of two ball rows ran only 380 and 780 r. p. m. and under loads from 380 to 1800 kg. An influence of the speed could not be definitely determined.

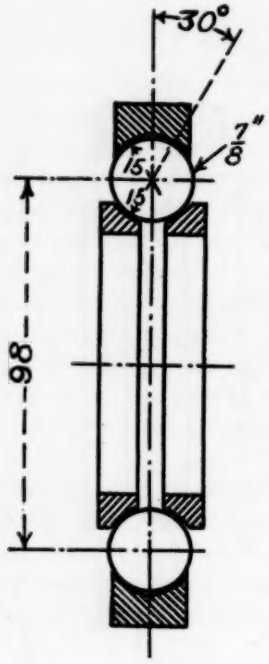

FIG. 24

For 380 kg. load, it gave $\mu_i = 0.0051$.

For 850 to 1800, $\mu_i = 0.0033$ to 0.0037.

The temperature ranged between 30 and 45 degrees C.

113 Under the highest load of 1800 kg. sliding and rolling frictions participate equally in the frictional work; with decreasing load the share of the sliding friction decreases while that of the rolling friction increases.

114 A heavy ball bearing, in order to replace a sliding journal of the best type, must have less frictional resistance than the journal in Fig. 23. This design is therefore not suitable for practical use.

115 In Fig. 24 the journal was also made up of two ball rows. At 380 and 780 r. p. m. and 1100 to 3500 kg. load it gave $\mu_i =$ 0.0052 to 0.0060. In an endurance test under 3500 kg. load at 780 revolutions per minute the temperature rose in three hours from 84 to 130 degrees C. without change of the friction coefficient.

116 With 3500 kg. journal load the sliding frictional work is almost 3.5 and with 1800 kg. it is still twice as great as that with rolling friction.

117 The remarks concerning the practical value of the journal of Fig. 23 apply even more forcibly to that of Fig. 24.

118 Investigation covered two journals, as shown in Fig. 25. The first was made before the beginning of the tests. At that time there were no available data for the permissible loads and the frictional values. It was also the first examined.

119 Merely the circumstance that several of the ball tracks still plainly showed grinding scratches developed that such journals require some time to get down to uniform running conditions. The journal was observed for five weeks, during which time it ran daily from two to nine hours. It developed that, as with my earlier experiments on cast iron worm gearing the state of uniformity, corresponding to a constant frictional value, was reached earliest for a given load by allowing the bearing to run for some time under a materially higher load. With our test procedure with step by step load increase and decrease this state of uniformity was soon reached for the lighter loads; it required more time for the heavier loads.

120 The investigation was finally terminated at 580 revolutions per minute and 4200 kg. load because two races showed damage. The observation at 780 and 1150 revolutions per minute therefore extend up to a load of only 2050 kg.

121 It would seem that since with the higher loads that were reached at each speed the journal had not yet got quite down to uniform running conditions, the reduction of the friction coefficient with increasing speeds as given in the following table should be partly ascribed to this condition.

122 The friction coefficient may therefore, for the slower speeds and higher loads, be somewhat smaller than that given. The following table gives the values derived from the readings:

R. P. M. =	65	100	190	380	580	780	1150
$P =$ 380 kg. $\mu_i =$	0.0095	0.0095	0.0093	0.0088	0.0085		0.0074
$P =$ 1100 kg. $\mu_i =$	0.0065	0.0062	0.0058	0.0053	0.0050	0.0049	0.0047
$P =$ 1800 to 4200 kg. $\mu_i =$	0.0055	0.0054	0.0050	0.0043	0.0041	0.0041	0.0040

$P =$ 1800 to 2500 kg.

123 With 1800 kg. journal load the work of sliding friction is one-third to one-quarter of the total frictional work. The design is therefore not bad so far as the frictional conditions are concerned. But the balls of the test journal are too small. To get acceptable frictional values, balls of $\frac{7}{8}$ inch diameter should have been selected.

124 The races of the second journal had well finished and polished ball tracks. It was made of different steel and was tested in order to give data as to the suitability of that. The load was rapidly raised beyond the permissible amount to 4200 kg. Under the heavy overload an outer race broke, before the heavy load got down to uniform running. The frictional values observed were therefore all slightly higher than those cited.

PERMISSIBLE SPECIFIC LOADS k

125 Balls and races in Fig. 21 acted perfectly at loads under 3000 kg. and all trial speeds up to 780 revolutions per minute. A few hours of endurance run with 4900 kg. at 780 revolutions per minute plainly showed slight variations in the hardness of the ball tracks. The softer places showed deeper impressions and looked darker than their surroundings. Under continued running, flat holes are formed at the soft spots, with edges more or less sharply defined in accordance with the peculiarities of the material.

126 Of the four journals, whose races were made of different steel, two showed up similarly. The races of the other two proved uniformly hard and withstood the test. But whereas with one the ball tracks were just barely noticeable, they were decidedly defined with the other.

127 These experiences indicate that 4900 kg. is an inadmissibly high load.

Basing 3000 kg. as a permissible load on these observations, gives k by calculation as below.

The load per ball row is 1500 kg. and with 14 balls the greatest load per ball is, according to Equation 11,

$$1500\frac{5}{14} = 536 \text{ kg.}$$

with

$$d = \tfrac{7}{8} \text{ inch: } k\,7^2 = 536$$

approximately,

$$k = 11$$

Taking $k = 10$ gives for a ball supported in a groove with a radius of curvature $= \frac{3}{4}\,d$.

$$P = 10\,d^2 \text{ } (d \text{ in eighths inch English})$$
$$P = 100\,d^2 \text{ } (d \text{ in cm.})$$

128 The journals of Fig. 25 were also loaded up to 4200 kg., but were damaged under this load. The ball track became sharply defined under an even smaller load. Even with uniformly hard ball races, this journal will hardly carry reliably more than 1800 kg. The outer ball races are the more heavily loaded; the average load on each of the central tracks is the 0.29, that on each of the side tracks the 0.23 part of the total journal load.

129 For the permissible load of 1800 kg. the corresponding amounts are 522 kg. and 414 kg. The central tracks each have 22 balls, so that the greatest load per ball approximates

$$522 \frac{5}{22} = 120 \text{ kg.}$$

For the side tracks, each with 20 balls, the greatest load per ball figures out

$$414 \frac{5}{20} = 104 \text{ kg.}$$

so that

$$k = \frac{120}{5^2} = 4.8$$

130 Note also that the relative movement between balls and outer races, where the greatest loads occur, is almost exclusively a rolling one. At the ball tracks of the central inner race, where the balls also slide and are, to judge from their appearance, amply loaded at 1800 kg. journal load, the greatest load per ball approximates 90 kg.

For these tracks we get

$$k = \frac{90}{5^2} = 3.6$$

For flat, conical and cylindrical track surfaces we have

$$P = 3\ d^2 \text{ to } 5\ d^2 \quad (d \text{ in } \tfrac{1}{8} \text{ inch English})$$
$$P = 30\ d^2 \text{ to } 50\ d^2 \quad (d \text{ in cm.})$$

131 The smaller values are to be used where there is simultaneous rolling and sliding friction at the points of principal load, the larger values when there is only rolling friction. The load $5\ d^2$ is already relatively high and is certainly nearer to the ultimate load at which inequalities of the material become disagreeably apparent than the load $10\ d^2$ given for the grooved cross section.

132 On reconsidering the results of the friction and load investigations we recognize that only the races illustrated in Fig. 21 are fully satisfactory for bearing journals. The use of such races gives us entirely practical dimensions for journal loads of 6000 and 10,000 kg. and frictional values responding to the most critical demands.

133 The German Small Arms and Ammunition Factories of Berlin have, for the past year, been proportioning ball bearings in accordance with this report.

134 There have been made there and carefully observed in practice ball bearings of widely differing designs, and it has been uniformly found that the statements here made hold good.

135 The investigations here reported were concluded in March, 1899. In continuation and concurrently with the German Small Arms and Ammunition Factories, Berlin, work looking to the further improvement of the larger steel balls and races has been carried on.

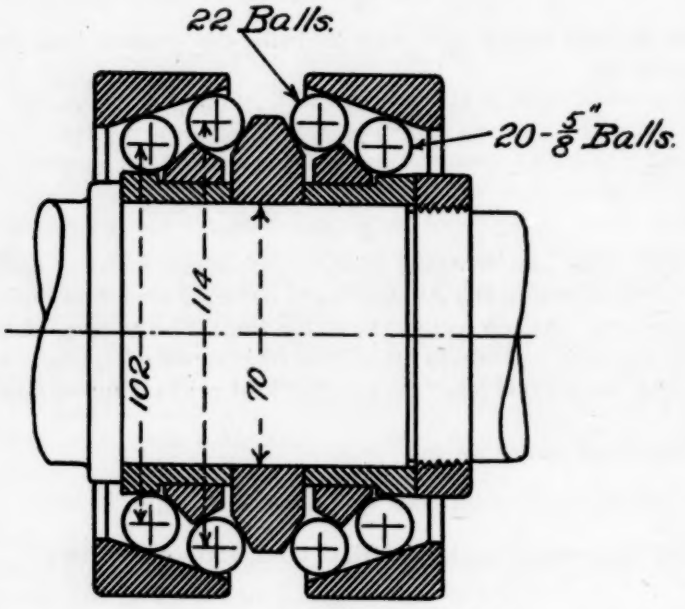

FIG. 25

It has been attended with success and resulted in the manufacture of balls and races that may be more highly loaded than those in which the results reported were reached. In examining such races a journal such as Fig. 21, but with only one ball row was for a long period submitted to a load of 4900 kg. at 780 revolutions per minute, this being the highest within the capacity of the friction weighing scale. Under this load, which is double the previous one, the ball tracks were barely marked and no difference in the hardness developed. According to experience so far, the permissible loads of balls and races may be taken 1.5 times as great as previously reported.

136 These frequent examinations have also shown that the ball bearings are very uniform as to their friction. The greater or lesser viscosity of the lubricant influences the friction but slightly. In many situations they possess various advantages over sliding journals.

137 The necessity for getting down to a uniform bearing which not infrequently seriously handicaps sliding journals, is eliminated with well made ball bearings. They are short, and even for high speeds and loads no larger than for low speeds, and are suitable under conditions where sliding journals must be made undesirably long to avoid seizing and to conduct away the heat generated. Dust and other uncleanliness in the oil, for instance, not perfectly removed cores, can more easily be kept off of the supporting surfaces and are less harmful than with sliding bearings.[1]

138 The reliability of ball bearings is the quality most generally doubted. After my first experience with them, I had no great hopes in this direction, but after observations that I have since made of properly proportioned and carefully made ball bearings, I incline to the decision that it is owing to their very reliability that they respond to extreme demands and that therefore their use is advisable even where sliding journals wear rapidly.

139 These good qualities are, however, found only in bearings whose balls and races are made with sufficient accuracy and that respond, as to uniformity, hardness and toughness, to certain requirements, the compliance with which will probably always remain the province of a very few specializing concerns.[2]

[1]Translator's Note: This must not be taken as a license to fill a ball bearing with dirt, grit, etc., which must necessarily reduce the surface and so destroy one of the very great advantages of the ball bearings, *i. e.*, its practical immunity from wear during the full lifetime of the mechanism it carries. Single row ball bearings permit the shaft to oscillate slightly, so that slight deflections of the shaft or slight errors in fitting do not appreciably affect their good action.

[2]See "Zeitschrift des Vereins Deutscher Ingenieure, Vol. of 1897, p. 968, and Vol. 1898, p. 1157.